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Continuity and Change in Rice Varietal Diversity in the Tamatave Region of Eastern Madagascar

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Abstract Rapid population growth and a mostly rural population depending on agriculture for their livelihood is putting increasing pressure on Madagascar's unique natural resources. Slash-and-burn (tavy) remains common in Eastern Madagascar, especially for growing rice, the most important food crop in Madagascar. In the face of declining yields due to soil degradation and ever shorter fallow periods, the Madagascar Fauna & Flora Group has been assisting farmers to find agroecological alternatives to increase rural revenues and improve food security and reduce pressure on remaining forests and protected areas. As crop genetic diversity is one key aspect in agroecology, we carried out a rapid survey in late 2019 to determine present varietal diversity in the villages around the Betampona Integral Nature Reserve in the Tamatave II District. We inventoried 81 varieties among the 73 households in the five fokontany surveyed, the majority of which were grown by one household only. The five most widely grown varieties were grown by 34-42% of households, often concentrated in one or two fokontany. A review of historical rice inventories revealed that many presently cultivated varieties were already grown in the 19th and early 20th centuries. Although more recently developed varieties have been adopted, and farmers are testing seeds recovered from purchased rice or emergency food donations, the old local varieties have characteristics (better adaptation to local soil and climate conditions; cultural importance; and culinary qualities) that guarantee their continued cultivation.

Keywords: *agrobiodiversity, rice varieties, Betampona Integral Nature Reserve, Madagascar*

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1. Introduction

Madagascar is well-known for its high level of biodiversity, with many endemic plant and animal species that are unique to the island. Despite the unique flora and fauna of Madagascar, very few native plants are used as food sources except in times of severe food insecurity caused be cyclones, droughts or fires. Recent research by [1] revealed that nearly 100% of the crops grown in eastern Madagascar are of foreign origin, having been brought to island since the first human settlement.

Rice (*Oryza sativa*, japonica type) was one of four crops brought to Madagascar by the first Austronesians settling on the island in the 8th century (the other crops were greater yam (*Dioscorea alata*), Indian saffron (*Curcuma sativa*) and coconut (*Cocos nucifera*) [2]. Rice was grown using the slash and burn method, which remains a common practice to this day especially in eastern Madagascar. A second wave of Austronesian migrants in the 14th century introduced irrigated rice varieties (indica type) and techniques, first settling around Maroantsetra [3]. As the high rainfall (on average, 3000 mm yr^{-1} along the north east coast of Madagascar) made control over water levels in rice paddies difficult, they later migrated to the central highlands where they built terraces, dams, and feeder and drainage canals, enabling year-round production of rice and other crops. In the roughly 1,400 years of rice cultivation in irrigated, swamp and rain-fed slash-and-burn systems, farmers selected numerous varieties (land races would be a more correct term) adapted to specific local soil and climate conditions. The agriculture research station of Lac Alaotra maintains a collection of 2,400 local varieties [4].

In the last half century, many more varieties have been developed through various directed breeding programs by FOFIFA and foreign assistance aimed at increasing rice production for greater self-sufficiency. In spite of that, yearly rice imports continue to increase from 3,000 Mg in 1899-1900 (due to a major outbreak of plague around that time) to more than 400,000 Mg at present. Rice is the main staple crop of the country with a mean annual consumption of 120 kg person^{-1} year^{-1}, ranging from a low of 91 kg in 1995 to a high of 148 kg yr^{-1} person^{-1} in 2014 [5]. Rice provides about 55% of calories in Malagasy people's diet.

Growing sufficient rice to feed the family remains a key strategy for farmers (albeit one that few families attain [6]), and remains a major policy objective for the government. Often, though, the focus of assisting farmers to increase production is on introducing new, high yielding varieties for irrigated rice production with little to no attempt to learn about existing diversity among rice varieties that may be better adapted to local edaphic and climate conditions, production methods, and cultural/culinary preferences. Genetic diversity is an important strategy in agroecology, and should be investigated before introducing new varieties. In this paper, we report about historical studies on the diversity and classification of rice varieties to provide context for present diversity of rice varieties in villages around the Betampona Integral Nature Reserve, 30 km upriver from the former Jardin d'Essais (research station) of Ivoloina, villages that were subject of a livelihood strategy study in 2013 [6].

2. Historical Studies of Rice Variety Diversity

A first enumeration of rice varieties grown along the east coast near Toamasina (Malagasy name for the town the French called Tamatavae) was made by Louis Armand Chapelier (1778-1806)[a]. His thirty-first letter of 21 January 1805 reported on his work on agrobiodiversity and included (among other crops) a list and short descriptions of 14 local rice varieties. Reference [7] annotated Chapelier's work, and translated the phonetically written names into in modern Malagasy (in parentheses): TC \f 1 "A first enumeration of rice varieties grown along the east coast near Toamasina (Malagasy name for the town the French called Tamatavae) was made by Louis Armand Chapelier (1778-1806).a His thirty-first letter of 21 January 1805 reported on his work on agrobiodiversity and included (among other crops) a list and short descriptions of 14 local rice varieties. Reference [7] annotated Chapelier's work, and translated the phonetically written names into in modern Malagasy (in parentheses in the text box

1 Vare Randranboulou (Vary Randrambolo) - panicles with alternate spikelets resembling bamboo; cultivated along forest edges, esp. in the Fito region. Grain with very white caryopses.

2. Vare Lava (Vary Lava) - Upland rice with long white grains.

3. Vare Manangue-helatch (Manana elatra) - winged rice. Reddish, round grain, lemma and palea bearing two extensions resembling wings.

4. Vare Soumoutch (Vary Somonitelo)[1] – rice with a very white caryopse and hairy husks of which 3 barbs much longer than the others. Cultivated mainly in swamps.

5. Vare Vouloune-danbou (Vary Volondambo; type of the previous) "hair of pigs". Very long panicles with many well filled spikelets; short, fat grains with husks ending in a reddish or violet awn resembling coarse pig/wild boar hair.

6. Vare arougan (Vary Harongana) - rice with yellow husk. Short, thick panicles with many spikelets; short yellowish paddy ending is a short red awn. Rice with very red caryopses; upland variety.

7. Vare foutci-terac (Vary Fotsy antsaky) - Rice which is born white. Swamp rice with red grains.

8. Vare manantzari (Vary Mananjari) - variety originating on the banks of the Mananjari river. Swamp rice, very white caryopses.

9. Vare souai-mahitsou (Vary Soamaitso) - good, beautiful rice of a blue-green color (referring to the whiteness of the hulled grain with a transparent, blueish color).

10. Vare Saboutic (Vary Sabotrika). Swamp variety with small, white roundish-oval grain.

11. Vare mouronne (Vary Morona) - rice from the river Mamouronne. Long panicles with sparse spikelets; hulled grain is oblong, medium red.

12. Vare loa n'akanga (Vary Lohan'akanga) - Rice resembling a guinea hen's head. Medium long panicles with a good number of spikelets; oblong grain with husks marked by 2-3 brown stripes; hulled grain is white.

13. Vare salazane (Vary Salazana) - Rice with brown or blackish lemma. Type of the previous which only differs in grains of not having distinct and regular brown stripes; but husks appear black or russet like the smoked clay of cooking platforms.

14. Vare lamba (Vary Lamba) - Rice with velvety lemma, white grain swamp variety. Long panicles with a good number of spikelets; grains long and fat. Hulls covered with short, white hairs, silky.

Rice was one of the 'local' crops tested at the Jardin d'Essais de l'Ivoloina, established soon after the French colonized the island in 1895. Research on local food crops was, however, mainly self-serving for the colonizers, as [8] wrote: "[In the jardins d'esssais] they developed indigenous species with special attention accorded to exportable plants. They also cultivated french vegetables in these gardens to meet the needs of resident Europeans." It was also customary at the time that to pay day laborers partially with rice.

The first rice trials at the Jardin d'Essais de l'Ivoloina (12 km northwest of the city of Toamasina along both sides of the Ivoloina river) took place in 1906-07 with several local land races (Betahava, Fotsy Ansaka, Angaziza and Varivato), with results published by [9] and [10]. Presumably, these were varieties that were commonly grown by farmers in the neighborhood of the Ivoloina station. A second trial was established in 1907-08 on several plots on the left bank section of the station with the varieties Varivato, Angazize, Arongana (Harongana), 'Caroline' [b], Betahava, Varibe, Somokatra, Volo, Mananelatra, Isakaomby, Bemalady, Bengale, Longotra, Lambamalady and Longo), but no published results of these trials were found.

In 1909, the then governor-general of Madagascar ordered the collection and centralization of all rice varieties being cultivated in Madagascar at the Nanisana Research Station (near, but nowadays a suburb of Anatananarivo) in order to enable a first classification of

1 This is most likely Vary Somotra, not Somonitelo (which means "Three awns" in Malagasy as interpreted by Fontoynont). The original description of Chapelier is "Rather long panicles, many well filled spikelets; short grain ending in one long awn" (Grappes assez longues; épillets nombreux et bien fournis: grain court et terminé par une longue barbe).

those varieties. The different research stations were asked to send in samples of paddy and hulled grains, a sheaf of panicles, as well as information about location of collection and production method [11]. Samples of 57 awned and 162 non-awned varieties were received, and classified according to criteria used for wheat varieties in Europe (in absence of a standard method for rice classification at that time), namely presence of awns; the length of the panicle (short, medium, long); color of the glumes and caryopses; and shape and dimensions (length, width and thickness) of the paddy and hulled grain. Table 1 shows the classification of the varieties from the Toamasina area only.

Table 1. Classification of Rice Varieties from the Toamasina Area (excerpted from [11]

Non-awned varieties	
Medium ears; white, medium grain	Bengaly, Bemalady, Soam[a]itso, Varibe, Vato, Vatobe
Medium ears with longue glumes	Bemahasoa mena
Long ears; white, medium grain	Betahavana, Fotsiantsaky, Kitrana, Maintina, Soamiketra, Varibe, Varimanitra
Long ears; red grain	Vary mena
Long ears; white, long grain	Belohalika, Mananara, Varikatrana,
Long ears; white, very long grain	Fotsiavaka, Joja
Awned varieties	
Medium ears; red, medium grain	Vary vato (also known as Ramihintsina)
Medium ears; red, long grain	Variraoka

Rollot, interim head of the Nanisana Research Station in 1909 (stationed at the Ivoloina Station from 1904 to the end of 1908), recognized that the list was far from complete, and acknowledged the difficulty of classification given many synonyms and homonyms among the samples received. Nevertheless, he considered all named rice samples to be deemed varieties unless proven otherwise. To determine whether or not that was the case, he established a trial in which blocks of three rows of each of the 219 varieties were sown in the same irrigated field during the main rice growing season of 1908-09 to eliminate any biases due to soil and weather conditions in the different districts of collection of the varieties. Due to an extreme drought in the March-May 1909 period, the flowers aborted and they were unable to obtain any results.

Since the 1920's, other researchers developed ways to classify the large number of traditional rice varieties [12-16]. In the absence of means of genetic analysis, these early efforts primarily used morphological characteristics of the seed (as paddy and hulled grain: length, width, thickness, shape, color, translucence, hardness). For some varieties, plant height at maturity, length of growing season, and range of yields were also mentioned. The use of length, width and thickness of paddy and hulled grain was, as [13] wrote, based on commercial standards for international trade that had been used earlier to classify traditional varieties from the central plateau of Madagascar: 1) very long and thick paddies, 10-11 mm in length; 2) medium long paddy of 8-8.5 mm, which constituted the majority of Madagascar rice varieties; 3) round and fat paddies of the Italian type, little cultivated; 4) very small paddies, almost round, 6 mm in length (cf. vary madinika); and 5) very long and skinny paddies, 10 mm in length, Bengaly rice type (known by local farmers as kalily or tsipla [tsipala] rice). Leroy thought tsipla may be a corruption of Ciphal, a province in British India, the place of origin of those rice types, but we did not find any such named place or province in old maps of India from that time. It refers more likely to the region of Cipala in west Java, ESE of Jakarta, one place of origin of the second wave of migrants to Madagascar in the 14th century. The classification developed by [14] was based on the color and the dimensions of paddy and hulled grain (grain length, width and thickness). They used the five groups considered by [12] to classify 80 rice varieties from different regions of Madagascar:

1. *Lava* (=long) - rice with long and large (fat) grains: paddy grains longer than 9-10 mm, and width >2 but more often ≥3 mm.
2. *Tsipala* (=long and slender) - rice with long, skinny grains: paddy grains ≥8 mm and width ≤2.5 mm. These authors noted that varieties in this group may have their origin in Bengal.
3. *Mahia* (=slender, meager) - rice with semi-long grains: paddy grains between 7 and 9 mm long, and a transversal width ≤2.5 mm.
4. *Madinika* (=small) - short-grain rice elliptic in form, ≤ 7 mm long and a width > 2.5 mm but mostly between 2.8 and 3.5 mm.
5. *Kiriminy* (=cream?) - small, white, hard and translucent grain with an average length of paddy ≤6.5 mm, with a width of ≤2.5 mm; primarily grown around Diego Suarez. "Cream" may refer to its glutinous character turning into porridge when cooked.

References [14-15] provided brief descriptions for each variety based on the criteria used and illustrated their work with photographs of the paddy and hulled grain side-by-side. In only a few cases did these authors mention a variety's mode of production (irrigated, swamp, upland) or yield. In the initial work published in 1929, they included only varieties with a potential for export to European markets; due to demand by colonial farmers for information on non-exportable local varieties, they published a second article in 1931 with information on 60 additional varieties from the same regions. Table 2 shows the rice varieties from the Tamatave area only; detailed descriptions of these varieties is provided in the supplementary material. This table shows primarily white rice varieties, which may be due to the initial focus on exportable varieties that were white, predominantly translucent and wouldn't crack during processing resulting in high percentage of broken grain (red rice and chalkiness/opaqueness were considered defects in exported rice, as noted by [12]).

Table 2. Tamatave Rice Varieties from the Tamatave Region from the Inventories of [14,15]

1929 inventory		1931 inventory	
Telovolana Vato patsa Manantsoa Mahagaga Anana Randrambolo Mandriravina	Bemanara Vondrona Tsivimbina Roka mena Bemahasoa Mahira	Kitrana Manana elatra Manasa manana Vary mena Roka fotsy	Sa[ha]laro Soamaitso Vary lava Vato rami-hintsana

Alternate spelling in [ ]; Roka fotsy/mena are synonyms for Betahava[na] fotsy/mena. [inserted Hrt here]

Reference [16] took [14-15]'s work as the point of departure for classification of 25 varieties grown in Western and Northwestern Madagascar. As he did not know of any varieties in the Kiriminy group grown in W and NW Madagascar, he only considered the first four types. He also found too little differences in the thickness of grains to use that as a classification criterium, so only considered length and width. Jumelle (a botanist) developed a dichotomous key successively considering different parts of the whole rice plant (except roots) to determine characteristics they had in common (and thus would be unusable for classification) and characteristics which varied more or less frequently, maybe not always but frequently enough to be usable for classification. Characteristics considered by Jumelle included:

- plant height and stem diameter at maturity;
- tillering;
- leaf length and width; upright or drooping; straight or twisting; pubescence;
- panicle length, # of nodes, # branches, #spikelets;
- relationship between length of inflorescence and flag leaf;
- dimensions and form of the spikelets/paddy
- color and length of awns/beards, if present
- color of the glumes, palea and lemma
- color of the pericarp of the caryopsis and whether opaque or translucent
- form of the hulled grain (cylindric, elliptic, compressed elliptic, compressed, oval)
- hardness of the husked grain;
- length of growing season;
- season of production; and
- type of production system (swamp, irrigated, upland).

Contrary to the above authors, who studied spikelet, grain and/or plant characteristics of varieties they had collected to classify these in larger groups with common, distinguishable characteristics, [17-18] focused on the names of traditional Malagasy rice varieties given the abundance of terms defining land races (populations) on the form of reproductive structures of rice plants. Grain form, size and color are characteristics that remain fairly constant in each cultivated population (generation), and introductions of new varieties could easily be distinguished [17]. Variety names described easily observable, adequately unique characteristics of the paddy, hulled grain, or the plant that farmers used (and still do) to distinguish varieties or point to the village or country of origin of a variety. In his conclusion, [18] compared his classification with those of [12-16] and grouped varieties based on six criteria:

- Caryopses characteristics, primarily color; odor (perfume (*manitra*)) and glutinousness ([*tsi] mandevy)* were only indicated as adjectives;
- Spikelet dimensions cf. the five types considered by [14] (*be, lava, tsipala [makalioka], mahia, madinika/kely*);
- color and pubescence of the glumes, palea and lemma; presence, color and length of awns;
- adherence of spikelets to the panicle, which determines ease of seed shedding/treshing.
- Panicle characteristics, such as length, branching, ...
- Leaf size, shape, pubescence, and orientation
- Stem characteristics such as tillering, number of nodes, distance between and placement of nodes, and stem strength/resistance to lodging esp. at maturity.
- Geographical origin within Madagascar (indicated by the name of a town or region) or country (Bengal [varieties named Bengaly, Beangaly or Bongala]; Java [zava]; Comoros [Kokomoja, Komoja, Komodza]).

A more recent study on rice varietal diversity was undertaken by [19] in 32 villages in the Vakinakaratra region in the central highlands of Madagascar, a region dominated by intensive irrigated production on terraced land. Radaniela noted that slash-and-burn (tavy) rice culture was expanding to meet rice demand due to population growth and growing scarcity of land suitable for terracing and irrigation. Radaniela's survey of varieties in use at the village level resulted in 349 varieties with distinct names, 306 grown in irrigated systems and 43 under rainfed conditions. Aggregated at the regional level and eliminating/consolidating synonyms and homonyms, this resulted in 134 irrigated and 14 rainfed distinct varieties. Thus, despite more extensive research and extension efforts in Vakinakaratra, the release of hybrid varieties, use of farm inputs and an extensive, well-maintained irrigation infrastructure, farmers continue to rely on a broad genetic diversity to ensure their livelihood.

In 2013, den Biggelaar directed a livelihood strategies survey among farmers living near Parc Ivoloina and Forestry station (sectioned off from the former Ivoloina Agriculture Research Station in 1960) as well as in villages around the Betampona Integral Nature Reserve (INR) 30 km upriver from the Ivoloina station. *Tavy* rice production predominates among the Betsimisaraka (the dominant ethnic group along Madagascar's east coast) in spite of the many laws and edicts against the practice by successive governments in the 19th and 20th centuries. Tavy is culturally important as a way to honor the ancestors even in the face of declining yields due to soil erosion/degradation and increasingly shorter fallow periods. Swamp (valley rice without active management of water levels) and irrigated production have gained popularity in the last 15 years, but expansion is limited as scarce valley land is already occupied and most hill slopes are too steep to terrace. Greater rice self-sufficiency, however, remains a key strategy for farmers, albeit one that few are able to reach [6]. Introduction of new hybrid varieties to get better yields are not a viable option given their dependence on external inputs to reach those higher yields, as well as the high cost and their unavailability. Over the last half century, rice research in Madagascar has focused mainly on improving varieties for irrigated systems, and less on developing varieties for swamp (horaka) and upland (tanety) rainfed cultivation using tavy.

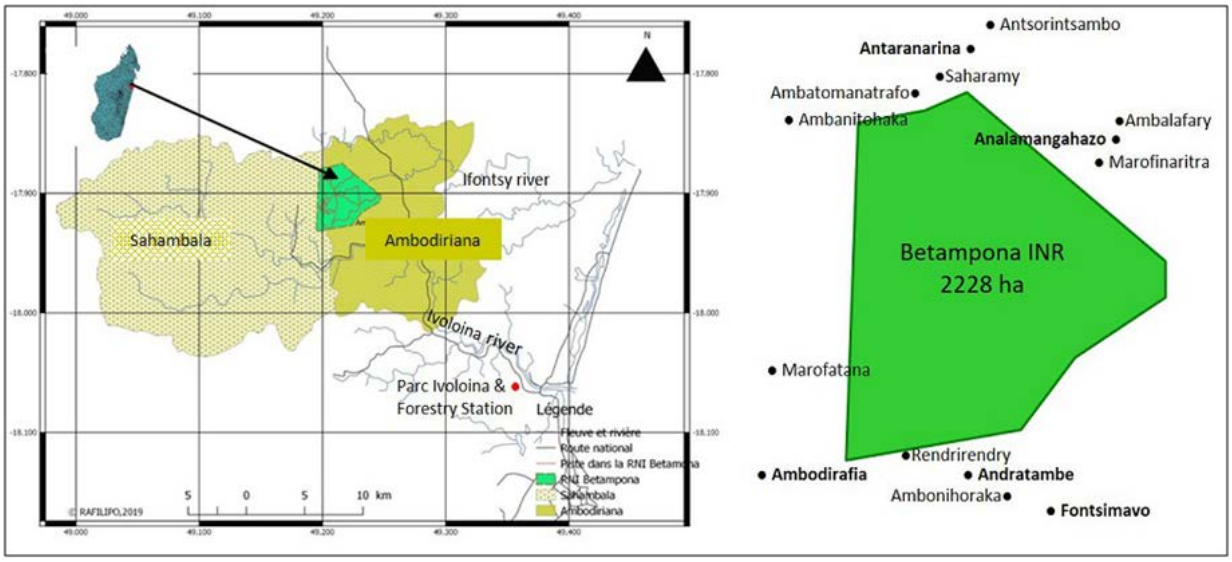

Figure 1. Location of the study area, fokontany and villages where the surveys were done

3. Methodology

Given the importance of rice in the diet and culture, and the declining yields affecting the livelihoods and food security of farmers in the Ivoloina valley [6], improving rice production for greater self-sufficiency is one of the objectives of the ecoagriculture initiatives of the Madagascar Fauna & Flora Group. To learn more about the extent of existing rice varietal diversity on farms around Betampona INR, we carried out a short, rapid survey with two objectives: (1) to identify the different varieties of rice that exist and are actively cultivated by farmers in the area around the Betampona INR; and (2) collect information about the basic characteristics of those varieties and their production methods (time of year, length of growing season, production system). The Betampona INR is located in the Toamasina II district, 40 km northwest of the city of Toamasina, Atsinanana region. The Reserve covers an area of 2228 ha, located in the rural communes of Ambodiriana and Sahambala. The survey was carried out between October and December 2019 in five fokontany (the lowest administrative unit) around the Betampona reserve: Fontsimavo, Andratambe, Ambodirafia, Antaranarina and Analamangahazo (Figure 1). Seventy-three randomly chosen households participated in the survey (5.5% of the total number of households in the five fokontany, based on the 2018 population census). We used a form to enter location and variety names; agronomic characteristics (horaka/tavy method, month of seeding/transplanting and harvest, length of vegetative cycle (in number of days or months), pericarp color, resistance or tolerance of flooding, drought, wind, insects and diseases. At the end of the surveys, we organized a community meeting in each fokontany to learn more about rice production practices and traditions, and discussions about varieties found.

Results were entered and analyzed in Microsoft Excel. The length of the vegetative cycle was calculated using both the reported number of days or months (the latter converted to days) if recorded, as well as from the reported time of year varieties were seeded/transplanted and harvested. November/December through May/June is the main (called *vary vato*) growing season depending on the start and end of rains; many farmers grow a second crop in their horaka and/or upland fields (using short season varieties) in the July to November *vary aloha* period. If only seeding and harvesting months were provided, we calculated vegetative cycle using the 15th of those months to obtain the cycle length in days. The number of days were then averaged from data of all households growing a particular variety.

4. Results

A total of 81 unique varieties were found in the peripheral zone around the RNI Betampona (Table 3). We considered varieties with the same name but with different colored pericarps or other designations (short, long, early, ...) as different varieties, as they may be genetically distinct. Respondents indicated that some named varieties have synonyms (Bekasaka mena = Vary vatomena and Tsiahofy = Zato andromena), making the total 79 unique varieties. Most of the varieties grown have a red pericarp and are glutinous (sticky), as red sticky rice is preferred by Betsimisaraka consumers; seventeen named varieties were found with both red and white pericarps.

Nearly two-thirds of the varieties (51, or 63%) we found are grown in *horaka* (swamps), given that two to three rotations are possible per year depending on the varieties chosen and availability of year-round wet swamp land or a stream for irrigation. On *tanety* (upland fields using *tavy* (slash-and-burn)), one rice crop is normally produced per year; only rarely is a short-season variety grown as a second crop on tanety in the July to October/November period. The time is too short and conditions unfavorable to prepare new fields in June.

As noted in the introduction, variety names are descriptive and primarily based on the characteristics of the panicle, and less frequently characteristics of the plant or place of origin. Translation of variety names can be found in the supplementary material. A couple of variety names were given by farmers experimenting on them during the time of the study; examples are Stock and Stock tampon. Stock refers to any imported rice (from

India, Pakistan, Myanmar, Thailand, Brazil) for sale in small stores and local markets, whereas Stock tampon refers to food security buffer stocks the government maintains (purchased from those same countries) and provided to people in case of emergencies such as cyclones, droughts, etc. Sometimes, people find unhulled grains in this rice which they recover and use as seed. Stock tampon was first grown in 2017. Sekalinina may have its origin in the child and maternal health and nutrition centers (called SECALINE) that provide supplemental food supplies as needed; rice provided for this purpose may have had unhulled grains, which people recovered and planted.

Table 3. Rice Varieties and the Number of Households by Farm System. Short-cycle, Second Season Varieties in Italics

Horaka (51)	Red	White	Horaka (51)	Red	White
Beforiaka			*Trepa hambo*		
Bekasaka			Tretrapontsy		
Bekoratsaka			*Tsy afohy*	5	
Bemaroko	7	1	Tsy ambidy	1	
rano	26	5	mamo	7	
Betahavana	2		Tsy mambovia	1	
Botraka	3		Vary vato	2	
Botraka hiva	1		Vato malaky	5	
Bresil	1		*Zato andro*	1	
Diara	1		_____	3	1
Felambilona	1	1	Tanety (30)	—	—
Fotsy	8		Abedimamo		
avarana	3	1	Behangaly	1	
Gony be		1	malady	1	
Hasaka		6	Bemahasoa	8	
Kitrana			Bemahasoa be	6	
Kaominina	2		Bemahasoa	24	1
Mme	8	2	malady	1	
Tsiavana	24		Bemaroko		1
Mahagaga	1	1	Betangala	1	
Maitsolava		5	Botraka		1
Makalioka	6		Fotsy antsaky	1	
Mamy	1	10	Jojo	1	
Mananara	3	6	Lohambitro	4	2
Maroanaka	2		Maintimalady	1	
Mazankatoka	1	2	*Manana helatra*	8	2
Patsa	5		Mandriravina	1	
Ramilogna	1		Primavera	1	1
Salazana	1		Randrambolo	1	
Sekalinina	2	1	Sahalaro	2	1
Stock	1	2	Sahamiketra	31	1
Stock	1		Sahamonina		1
tampon		1	Salazana	4	2
Stylo	6	1	Somotra		1
Telovonana		19	Telovolana	1	
Trepa fohy			*Tsy mirekirekitra*		
Trepa					

4.1. Geographic Distribution of Varieties

The majority of varieties (55%) are grown in only one fokontany. Only five varieties were grown in all five fokontany, and another five in only four fokontany (Table 4). However, even if grown across the area, it usually concerned only one or two households in a fokontany, as was the case for varieties Tsiahofy and Zato andro mena.

We also found an unequal distribution of some varieties: 23 out of 26 farmers growing Bekasaka were from the fokontany of Ambodirafia and Antaranarina; and 20 out of 26 farmers growing Bemahasoa lived in Antaranarina and Analamangahazo. This may a reflection of (1) the earlier settlement of the area east of the Betampona Reserve, where Bemahasoa was the most frequent cultivated variety in the area north of Tamatave a century ago [14]; or (2) due to extension efforts and rural development projects having introduced new varieties in those areas in the past. Bekasaka was an improved variety developed at the Lac Alaotra research station in the 1950's. Bekasaka was the standard against which performance of other local varieties was evaluated in regional pre-extension trials at the Ivoloina Research Station in the 1960's [20]. Trepa, Mme Tsiavana and Diara are more recent introductions, as their names do not occur in past variety inventories.

The high percentage of unique varieties at the level of fokontany is also seen at the level of villages within each fokontany (Table 5). Sixty-three to 80% of varieties in each fokontany were found in only one village within that fokontany. Some varieties are grown in one village only, sometimes by several farmers, such as Vary Hasaka and Bekoratsaka fotsy by six and three households, respectively, in Ambodirafia; and Bemaroko rano and Felambilo by three households in Fontsimavo (the survey in this fokontany was done in only one village of the same name). Thus, it appears that even within relatively short distances between villages within a fokontany, there is little sharing of varieties, which may be due to close relationships between households with common ancestors in a village each having their own varietal preferences. On average, households grow two to three varieties - usually one on tanety as only one cycle is possible per year, and two in horaka.

Table 4. Number of Fokontany in Which Different Varieties Are Cultivated

Variety		Variety	
5	Bekasaka mena Bemahasoa malady Mme Tsiavana mena Sahamonina mena Tsy ahofy	2	Bekoratsaka fotsy Kitrana Maintimalady mena Makalioka fotsy Mananara mena Maroanaka fotsy Mme Tsiavana fotsy Patsa mena Sahamiketra mena Sekalinina Somotra fotsy Somotra mena Tsimambovia Vary vato Zato andro mena
4	Beforiaka mena Kaominina Makalioka mena Mandriravina mena Trepa fotsy		
3	Bemahasoa Bemahasoa be Diara Mananara fotsy Trepa hambo mena Trepa mena		

Table 5. Number of Varieties Cultivated in Each Fokontany and Villages Within a Fokontany (n = Number of Farmers/Households)

	# varieties	Mean # per household	Varieties in common	varieties in 2/3 (2/4) villages	Varieties in 3/4 villages	varieties unique to one village
Fokontany Ambodirafia (n=16)	35	2.2	4	8		23
Ambanitohaka (n=2)	12	6				
Ambodirafia (n=9)	16	1.8				
Marofatana (n=5)	23	4.6				
Fokontany Andratambe(n=6)	21	3.5	0	6		15
Andratmabe (n=3)	17	5.7				
Ambonihoraka (n=1)	5	5				
Rendry-Rendry (n=2)	5	2.5				
Fokontany Antaranarina (n=26)	37	2.4	2	2	8	25
Antaranarina (n=14)	27	1.9				
Ambattomanatrafo (n=6)	12	6				
Antsoritsambo (n=5)	10	2				
Saharamy (n=1)	5	5				
Fokontany Analamangahazo (n=13)	31	2.4	2	4		25
Analamangahazo (n=3)	9	3				
Marofinaritra (n=4)	16	4				
Ambalafary (n=6)	13	2.2				
Fokontany Fontismavo (n=12)	22	1.8				
Fontisimavo (n=12)	22	1.8				

Table 6. Mean Length of the Vegetative Cycle Reported by Respondents

Variety	**#days**	**Variety**	**#days**
Bresil	90	Mananara mena	153
Telovolana fotsy	95	Mazankato	
Telovolana mena		Patsa fotsy	
Zato andro fotsy	107	Randrambolo fotsy	
Trepa mena	113	Sahamiketra mena	
Behangaly malady	120	Salazana fotsy	
Botraka hiva	122	Sekalinina	
Mamy		Stock	
Manana helatra		Stock tampon	
Maroanaka fotsy		Bemaroko rano	166
Maroanaka mena		Mme Tsiavana mena	168
Primavera		Sahamonina mena	
Ramilogna		Patsa mena	171
Sahalaro		Bekasaka mena	174
Salazana mena		Bemahasoa be	177
Stylo		Makalioka mena	
Trepa fohy		Beforiaka mena	180
Tsy mirekiretra		Vary vato malady	
Trepa fotsy	125	Bekasaka fotsy	183
Hasaka	128	Betangala	
Trepa hambo mena		Fotsy avarana	
Zato andro mena		Gony be	
Botraka	131	Jojo	
Kitrana		Lohambitro	
Somotra mena	133	Maitsolava	
Maintimalady fotsy	137	Mme Tsiavana fotsy	
Maintimalady mena		Randrambolo mena	
Mandriravina fotsy		Sahamiketra fotsy	
Mandriravina mena		Sahamonina fotsy	
Kaominina	140	Somotra fotsy	
Felambolina	143	Tretrapontsy	
Tsy ahofy	144	Tsiambidy mamo	
Abedimamo	150	Tsimambovia	
Betahavana	153	Bekoratsaka fotsy	190
Fotsy antsaky		Bekoratsaka mena	200
Mahaga			

4.2. Varietal Characteristics

4.2.1 Vegetative Cycle

The length of the vegetative cycle ranged from 90 days (Bresil) to 200 days (Bekoratsaka mena) (Table 6). Most varieties have cycles of 153 to 183 days, roughly the length of the main December through May/June growing season. Several varieties have the same name and cycle length, but with different colored caryopses (red or white). However, the cycle length is longer for the white types of Bekasaka, Mme Tsiavana, Samiketra, Sahamonina, Salazana, Somotra, and Trepa compared the red types of these same varieties. The opposite is the case for Makalioka, Patsa, Randrambolo and Zato andro mena, where the red types have longer growing seasons than the white types. The different color and cycle length indicates that they are distinct varieties, even as phenotypical/morphological characteristics (the basis for naming local varieties) are similar. As mentioned earlier, farmers informed us that two pairs of named varieties are synonyms: Bekasaka mena = Vary vatomena; and Tsiahofy = Zato andromena. However, their vegetative cycles are significantly different: 174 vs. 159 days for the first pair, and 144 vs 128 days for the second pair. The 15/16-day difference could be due to local variations in soil and weather conditions, but it is large enough to think they may, in reality, be distinct varieties rather than the same varieties with different names.

4.2. Other Variety Characteristics

4.2.2. Other Characteristics and Observations

We did ask informants about the sensitivity of varieties to inundation, drought, wind (lodging), pest and diseases, but did not receive responses from all informants and for all varieties. Pest and diseases were the main concerns common to all varieties.

The varieties Sahamonina, Bemahasoa malady, Trepa mena hambo, Mananara fotsy and Felambolina were mentioned as being very sensitive to wind. Sahamonina and Bemahasoa malady were also considered very sensitive to inundation. Mahagaga was mentioned as being difficult to dry after harvest. Mananara fotsy was considered to be adaptable to different soils, whereas Randrambolo was mentioned as being picky about soil type. Fotsy antsaky can be cultivated on tanety as well as in horaka, giving farmers more flexibility on when and where it can be grown. Respondents mentioned that Mananara fotsy, Madame Tsiavana, Tsy ahofy and Sahamonina could be planted twice per year; some farmers mentioned planting Telovolana three times per year, giving its very short cycle of three moons.

5. Conclusion

Historical studies on rice varietal diversity documented and described many varieties in existence at that point in time, but provided no information on the extent of their cultivation by farmers in specific areas. It was, perhaps, assumed that if a variety was present in an area, it would be grown by most households in that area. Actual diversity was likely much greater than the historical studies showed.

Our study found that there remains a significant rice varietal diversity in the study area; this may be by default as no new, more productive varieties are available/ accessible, or traditional varieties have characteristics (ecological adaptation, and cultural significance, and/or culinary properties) that farmers value and prefer. A majority of varieties is being grown by only one or two households, which may be an artefact of the small sample of households who participated in the study. A greater number of households could perhaps have reduced the number of varieties grown by one or two households only, but may equally well have turned up additional varieties. The larger number of respondents in Antaranarina did not result in a greater number of varieties in common among households.

We only inventoried varieties presently cultivated by farmers, and did not ask about varieties that they cultivated in the past and the reasons why they discontinued the cultivation of these. Nevertheless, a high varietal diversity was also found by Radaniela in the Vakinakaratra region in 2010, and so it may be characteristic of Malagasy agriculture for farmers to maintain high varietal/genetic diversity in their main staple food crop.

Farmers also carry out some selection work and experimentation with ‘new’ varieties derived from unhulled seeds recovered from food aid donations and imported rice. Examples are the varieties Stock (the name commonly used to refer to all imported rice for sale in Madagascar); Stock tampon (food security buffer supply), Bresil, and Stylo (the latter so named because the seed is very pointed, resembling a pencil). These imports form an increasingly larger share of rice consumption in the face of declining yields, even in remote rural areas such as the villages around the Betampona INR. Whether or not these experimental varieties will be adopted by more farmers, or for a longer duration is not known.

A number of varieties we encountered in our study were included in past inventories: Fotsy antsaky, Manana elatra, Randrambolo, Salazana and Somotra were described by Chapelier in 1806. Betahava[na], Fotsy antsaky, Manana [h]elatra, and Vary vato were subject of trials at the Ivoloina Research Station in the 1905-1908 period. Bemahasoa, Betahavana, Fotsy antsaky, Kitrana, Manana elatra, Mananara and Vary vato were included in Rollot’s 1909 classification of varieties from the Tamatave area. Francois and Chauffour’s 1929 and 1931 studies included the varieties Bemahasoa, Kitrana, Mahagaga, Manana elatra, Mandriravina, Randrambolo, Roka mena/fotsy (synonym for Betahavana mena/fotsy) and Telovolana from the Tamatave area. Whether or not any of these varieties are identical to the similarly named varieties cultivated at present is not known. It should be born in mind that farmers distinguish and name varieties primarily based on morphological characteristics of the panicles and grains, secondarily on other aspects of the rice plant. If a (new) variety is introduced in a village that is morphologically similar in appearance to a named variety already cultivated, it may be given a new name in that locality, resulting in synonyms. Conversely, if it has distinct characteristics and is not yet known in a village or

by a farmer, it may be given a name already used elsewhere, resulting in homonyms. Renaming is often done with new varieties bearing letter-number codes released by research, extension or rural development projects, as [19] also noted in his study.

The persistence of varieties/land races (or, at least, varieties with similar morphological characteristics bearing the same names) from the early 19th century into the present indicates that these varieties offer certain advantages (ecological, cultural, culinary) that ensure their continued cultivation. Only DNA analysis can provide conclusive answers whether they are identical to similarly named varieties described and classified in the past, but this may not be possible in absence of reference material of those varieties. To answer the question whether or not varieties we inventoried in our study are distinct, or may be synonyms or homonyms, we are in the process of doing DNA analysis and will report the results in a future paper.

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Notes

a Louis Armand Chapelier was born in 1778; his father was gardener of the Count of Barbençon at the chateau Maucreux near Villers-Cotterets (Aisne). At the age of 13, he gained employment at the King's Garden, and befriended André Thouin (agricultural botanist). In 1794, he departed for Madagascar as naturalist-traveller, where he established himself at Isatrano along the Ivondro river, south of Tamatave. He assisted André Michaux who arrived in 1802 with planting the various fruit species the latter brought with him from Mauritius. Michaux died less than a year later from fevers, and was buried at Isatrano. Chapelier died at the age of 28 on 6 december 1806 in the village of Ambodiatafana, a coastal village about 20 km north of Tamatave. He was also buried at Isatrano [21].

b Reference [16] noted that Vary lava is the most beautiful rice of Madagascar with long, translucent grains sold under the name "Caroline Madagascar." The word for the color of rice with golden-yellow chaff in Malagasy is *volamena*. The name "golden rice" grown around Charleston, South Carolina alludes to the origin from a lot of seed given by a captain of a ship blown off course on its trip from Madagascar to England. (https://www.seriouseats.com/ carolina-gold-heirloom-rice-anson-mills).

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Supplemental Material

Varieties from the Tamatave area inventoried in 1929 and 1931 [14 – 15]
(Varieties still cultivated in the study area at present in bold)

Name of variety	Dimensions (L, W, T in mm)[1]		Paddy color	Barbed	Caryopsis Color	Kernel properties[2]	Cycle length (days)	Plant height (m)	Yield (Mg/ha)
	Paddy	Hulled grain							
Anana	8.9, 3.2, 2.2	6.5, 2.9, 2	red ochre		white	H, T/SC	150	1.45	1.5 - 2.0
Bemahasoa	8.9, 3.2, 2.2	6.6, 2.8, 2	grey ochre, white		red	S, T/C	180	1.40	1.4 - 1.8
Bemanara	8.8, 3, 2	6.3, 2.6, 1.8	ochre		light grey	SH, T	180	1.60	1.4 - 1.8
Kitrana	8.6. 2.7, 2.1	6.3, 2.4, 1.9	grey ochre	barbed	red	SH, SC	135	1.30	1.2 - 1.6
Vary lava	10, 3, 2	7.1, 2.6, 1.8	light straw		white	H, T/SC	120	1.60	1.8 - 2.5
Mahagaga	8.8. 2.2,2.1	6.6, 2.5, 1.9	light straw w/ black spots		white	VH, T	180	1.50	
Mahira	9, 2.3, 1.9	6.6, 2.3, 1.9	light straw		white	VH, T	100		1.5
Manana elatra	9.4, 3.2, 2.2	6.9, 2.8, 2	dull light straw	barbed	white	H, T cracked	120	1.45	1.2 - 1.8
Manantsoa	8.1, 2.7, 2	5.9, 2.4, 1.8	red ochre		white	VH, T			1.8 - 2.0
Manasa manana	8.7, 3, 2	6.4, 2.7, 1.9	light straw		red	H, T/SC	120	1.30	1.2 - 1.5
Mandriravina	8.9, 2.9, 2	6.7, 2.6, 1.8	light straw	one glume barbed	white	SH, C	150		
Vary mena	7.7, 3.2, 2.2	5.5, 2.9, 1.9	dark ochre, white glumes		red	SH/C	150	1.35	1.5 - 2
Randrambolo	8.3, 2.9,2.1	6.3, 2.6, 1.9	light straw		white	H, T/C			1.4 - 1.8
Roka (Betahavana) fotsy	7.8, 3.1, 2	5.8, 2.8, 1.8	light straw	barbed, 3.5-5mm	white	H, T/SC	120	1.50	1.3 - 1.6
Roka (Betahavana) mena	8.3, 3, 2.1	6.3, 2.8, 1.9	ochre, some black	barbed	red	SC	120		1.3 - 1.6
Sa[ha]laro	9.3, 3.1, 2.1	6.8, 2.8, 2	light straw		white	SH, C	180	1.35	1.5 - 2
Soamaitso	8.8, 3, 2.1	6.5, 2.7, 1.9	grey ochre		red/rose	SH, T/C, cracked	150	1.30	1.2 - 1.8
Telovolana	9, 2.9, 2.2	7.1, 2.7, 2	light straw	barbed	white	H, T	95	1.45	1.5 - 2.5
Tsivimbina	9.5, 2.8, 2	7.2, 4, 1.8	light straw	barbed, 5mm	white	T	120	1.50	1.2 - 1.8
Vato Patsa	9.7, 2.2, 2	7.2, 2, 1.8	reddish brown		white	SH, T	180	1.60	1.2 - 1.5
Vato ramihintsana	8.8, 3.2, 1	6.5, 2.2, 1.8	grey ochre		red/rose	T/SC, cracks easily	180	1.30	1.5 - 2
Vondrona	9.1, 3.1, 2.1	6.8, 2.7, 1.8	ochre, with some black		white	VH, T	150	1.40	1.0 - 2.0

1 Paddy and caryopses dimensions = Length, Width, Thickness

2 Kernel properties: H=hard; SH=semi-hard; VH=very hard; S=soft; T=translucent; ST=semi-translucent; C-chalky; SC=semi-chalky

The Meaning of Rice Variety Names [4], [17]: Prefixes and adjectives for rice variety names

Be / -be	Before variety name means variety is productive/high yielding; if adjective after the name, it refers to the size of the grains compared to 'normal' type of the variety (large, stocky but relatively long)
Madinika	Small grain types with spikelets less than 5mm long
Mahia	Slight, meager, refers to the slender kernels of variable lengths
Lava	Long, reference to the long and large spikelets and kernels
Kely	Short and skinny kernels
Ambo	Tall
Botry	Stunted, dwarfish
Kely	Small
Fohy	Sort, little
Hiva	Low
Mena	Red, in reference to the color of the hulled rice as well as the presence of anthocyanins in the vegetative parts of the rice plant
Fotsy	White color of caryopses
Mainty	Black, refers to numerous rice types with dark colored (black to deep violet) glumes or upper tips of the inner chaff scales
Volamena	Varieties with golden yellow glumes
Lalaina	To be held dear
Malady	"Precocious"; adjective to applied to early ripening varieties
Malaky	"Quick"; adjective to short cycle varieties
Mamy	"Sweet"
Manitra	"Perfumed"; varieties that produce a good smell during cooking and have an agreeable taste
Soa-	"Beautiful/good"; used as prefix for many Vato varieties
Variety names	
Abedimamo	"To be in trouble" (*abedi*) and "being drunk" (*mamo*); variety for making alcoholic drinks
Antsaky	"Color of white cheese"
(H)Arongana	"Rapidly growing"; also, deep red in color like the sap of the Harongana tree (*Harongana madagascariensis*)
Avarana	"To pour"; meaning not clear
Beforiaka	Extremely productive; an old, famous rice variety in Madagascar
Beka[z/s]aka	"Large coat"; in reference to the large and thick spikelets, which produce a lot of chaff when milled
Bekoratsaka	Productive with very white caryopsis
Bemahasoa[be]	Variety originating from the village of Mahasoa; very advantageous, high yielding [with larger grains]
Bemalady	Very early (short season), often used synonymously for Telovolana and Haingana
B[i/e]tahavana	"Will fill the stomach"; reference to its high yield and good taste; syn. Roka
Botraka	"Globulous caryposis" (*botra*);
Diara	"Wagon wheel" (*kodiriana*); allusion to the shape of the panicle having many secondary branches resembling spokes
Felambilona	"Flower" (*felana*) and "grass" (*bilona*); variety with panicles that look like similar to grass cut for forage
Fotsiansaka	Irrigated rice variety with white grains
Gony [be]	"Gunny sack"; Productive variety that fills a gunny sack [with large grains]
Hasaka	"Good, valuable"
Jojo	"Advancing quickly" (short cycle variety)
Kitrana	"Rattle sound"; variety with hard, dark glumes rattling when shaken
Kaominina	"Commune"; recent variety originating from the commune of Mangabe, north of the study area; this may be the improved variety X265 that the mayor of the commune purchased and distributed to farmers after a cyclone destroyed much of the rice harvest and thus farmers' seeds for the following year as well.
Laingo	Having tender, light green leaves
Lohambitro	"Rabbit head"; variety with spikelets with small 'shoulders' resembling a rabbit head
	Madame Tsiavana "Madame doesn't have to weed"; vigorous variety that outcompetes weeds
Mahagaga	Name of place where seed originated; also "Amazing", in reference to high yield
Mahanoro	Name of place where seed originated

Maintimalady	Early variety with black/dark violet tipped spikelets
Maitsolava	Variety with tender long green leaves
Makalioka	Uncertain word origin; commercial name of varieties with very long, slender grains
Mambov[r?]ia	“Shorten, cut off the end”; perhaps reference to the rather short panicles
Mananara	Name of place where seed originated
Manana [h]elatra	Varieties with a winged appearance with inner and outer chaff of equal length
Mandravina	“Which (re)produces leaves”; variety that regrows from stubble after harvest
Mandriravina	“Sleeping leaves”, variety very sensitive to lodging
Maroanaka	“Having many children”; irrigated variety which tillers profusely
Mazankatoka	Variety with thick, dense panicles looking like a hair braid
Patsa	Shrimp, in reference to the form of the kernel that is bend like a shrimp
Randrambolo	“Hair braid”; in reference to the short, dense panicles
Ramilona	“To be soaked/steeped”; variety for irrigated production
Rojo	“Difficult to bear”; varieties with spikelets much shorter than Varilava but equally large; very productive variety. Also, the commercial name for rice with the largest grains
Raoka/Roka	“Gathered up in a mass by hand without reaping”
Sahalaro	“Mixture of the country”; mix of multiple local varieties
Sahamonina	From field (*saha*) and community (*monina*); generic name for local varieties
Salazana	Name of place where seed originated
Samiketra	“Weak/without rigidity”; sensitive to lodging
Sekalinina	Community center used for mother/baby clinics; may refer to seeds recovered from rice donations received there
Somotra	“Beard”, refers to varieties with awned or semi-awned spikelets
Telovolana	“Three months”; early varieties harvested 100-120 days after transplanting
Tretrapontsy	“Easy to clean” (*tretra*) like a banana [*fontsy*]); variety that is easy to hull
Tsiafohy	“Something very valuable that you are not giving away”
Tsiamidy [mamo]	“Not to be sold” [for making alcohol]
Tsy mirekirekitra	“Not sticky”
Tsivimbina	Cannot be held in one’s hand; reference to high yield. Tsima[ha]mbovia “Which one doesn’t harvest with a hoop net”, refers sometimes to rice types resistant to lodging but with mediocre yields
Tsipala	Having long and skinny grains (indica rice)
Tsokaomby	“Zebu bone marrow”, allusion to consistency and taste of rice cooked with this variety
Vato	“Stone, rock, weights”; varieties with grains looking like small pebbles similar in shape to madinika, but much larger
Vatomandry	Name of place where seed originated
Zato Andro	“Hunderd days”

Rice Varieties Inventoried in Each Village and Fokontany (in bold)