Genet Resour Crop Evol (2019) 66:415–427
https://doi.org/10.1007/s10722-018-0720-8

RESEARCH ARTICLE

Phenotypic characterization of dryland rice (*Oryza sativa* L.) germplasm conserved in situ (on farm) in a crop-diversity microcenter in southern Brazil

Tassiane Terezinha Pinto · Juliana Bernardi Ogliari · Otavio Rechsteiner Maghelly

Received: 12 July 2018 / Accepted: 7 November 2018 / Published online: 1 January 2019

Abstract In the far west of the state of Santa Catarina (FWSC) in southern Brazil, rice is produced from landraces grown in a dryland system, with production focused on household consumption. We characterized 60 local landraces of dryland rice and three improved cultivars from EMBRAPA—Arroz e Feijão for phenotypic diversity based on morphological characteristics. The landraces were collected in 27 rural communities of two municipalities in FWSC. Twenty-one morphological groups (MGs) were identified through the use of the Unweighted Pair Group Method with Arithmetic Mean clustering algorithm. Of these 21, 12 were represented by a single landrace. Grain morphology could be used both to distinguish among landraces and to identify different phenotypes within landraces. The geographical distribution of MGs seemed to be completely random. Of the 60 landraces, 35 presented a mixture of characteristics of the Indica and Japonica Groups; 24 presented only characteristics of the Group Indica; and four presented characteristics of Japonica. This finding is intriguing, since rice varieties adapted to dryland agriculture in Brazil generally have genic affinities to the Group Japonica. A clustering analysis based on both qualitative and quantitative characteristics identified four isolated populations and the formation of four groups (cophenetic correlation = 0.82). Some landraces from this study are being subjected to evaluation for their agronomic potential, to be followed by individual selection with progeny testing. This breeding approach is being proposed as a tool to support in situ/on farm conservation of rice landraces in FWSC.

Keywords Germplasm characterization · Morphological groups · Rice landraces · Genetic diversity

Tassiane Terezinha Pinto: Part of the doctoral thesis presented by the first author at the Federal University of Santa Catarina.

T. T. Pinto · J. B. Ogliari (✉) · O. R. Maghelly
Núcleo de Estudos em Agrobiodiversidade (NEABio), Universidade Federal de Santa Catarina (UFSC), Rodovia Admar Gonzaga, 1346, Caixa Postal 476, Bairro Itacorubi, Florianópolis, SC CEP 88034-001, Brazil
e-mail: juliana.bernardi@ufsc.br

Introduction

Oryza sativa L. is produced on all continents except Antarctica, being the staple food for almost half the world's population (Prasad et al. 2017). Brazil is the largest producer and consumer of rice outside of Asia (Brasil 2018), highlighting its ranking as the world's tenth-largest producer in the 2016–2017 harvest. Santa Catarina, in southern Brazil, is one of the most productive Brazilian states with 1.10 million tons of production (FAO 2004; Padrão 2018).

Rice-production practices in the Americas are quite diversified, due in part to the wide range of relevant agroclimatic conditions (Barbosa-Filho and Yamada 2002; Fageria et al. 2014; Singh et al. 2017). Commercial production in Santa Catarina is predominantly conducted in irrigated cropping systems in the lowlands near the Atlantic coast (Fageria et al. 2014). In the other regions of the state including the far west, outside the commercial production circuits and where irrigation is impractical, rice is grown by small-scale farmers in a dryland system using local varieties, aiming specially at self-consumption and consequent, local food security (Pinto et al. 2018).

The 'National Catalogs of Rice Cultivars' (Embrapa 2013) do not recommend any suitable cultivars for rainfed agriculture in the southern parts of Brazil. The identification of locally adapted rice varieties and those carrying special qualities becomes a first step to support the development of this alternative production system in southern Brazil. The cultivation of dryland rice for commercial purposes can be a source of income for the farmers, especially if they meet specialized market segments for traditional products, wherein cost–benefit ratios may be compensated more by the aggregation of special values and less by high yield potential. In addition, the dryland system is a promising alternative for areas with scarce water, with potential incomes comparable to irrigated rice, considering the possibility of targeted, long-term genetic improvement (Kato et al. 2009).

Previous studies characterized the genetic basis of Brazilian rice cultivars as narrow, resulting in relatively small, recent genetic gains, serving only to maintain past levels of productivity and genetic vulnerability, both for irrigated (Raimondi et al. 2014) and dryland rice (Da Silva et al. 1999). On the other hand, the genetic diversity of traditional varieties has been pointed out as being high (Abadie et al. 2005; Brondani et al. 2006), indicating that landraces may be a good source of variability to be exploited by genetic improvement programs. Recent studies suggest high levels of diversity in landraces of dryland rice conserved in FWSC (Gonçalves et al. 2013; Pinto et al. 2018), although their potential and real values are still poorly understood.

Therefore, this study is aimed at characterizing the diversity of 60 local landraces of dryland rice conserved in situ/on farm in FWSC and three cultivars improved by the Centro Nacional de Pesquisa de Arroz e Feijão da Empresa Brasileira de Agropecuária (CNPAF/EMBRAPA), based on morphological characters. The knowledge of the magnitude of this diversity at the *O. sativa* L. Group and morphological group levels can contribute to the expansion of the genetic base of this crop in Brazil, besides generating technical and scientific support for the implementation of a program of rice genetic improvement for the dryland regions in Southern Brazil.

Materials and methods

Plant material and characterization

Sixty local varieties of dryland rice from 27 rural communities of the Anchieta and Guaraciaba municipalities in FWSC (Fig. 1) and three improved cultivars developed by CNPAF/EMBRAPA were evaluated for morphological characters. These 63 entries were evaluated at the experimental farm of the Federal University of Santa Catarina, in Florianópolis-SC.

The experiment was conducted with a randomized complete block design with two replications. Plots were composed of three rows, 2.0 m long, spaced 0.5 m apart, with a plant density of 1,100,000 plants ha^{-1} after thinning and a final stand of 55 plants per linear meter. The evaluations of the descriptors were made within the central row, excluding one plant from each end.

Fertilization was performed as recommended by SBCS (2004), based on the results of soil analyses. Weed management was done manually whenever necessary.

Characters were evaluated according to the minimum rice culture descriptors published by Ministério da Agricultura, Pecuária e Abastecimento (MAPA) (Brasil 1997) and Bioversity (Bioversity International et al. 2007). Each descriptor was evaluated from ten competitive plants of the useful plot area. For the characterization of treatments, the greatest frequency state was used for the qualitative descriptors and, in the case of the quantitative descriptors, the average of the useful plot was calculated. Lodging was evaluated immediately before harvesting by counting the number of plants laying down per useful area of plot. The grains were husked with an MT 81 (Suzuki) mini-engine. Morphometric analyzes of the grains were

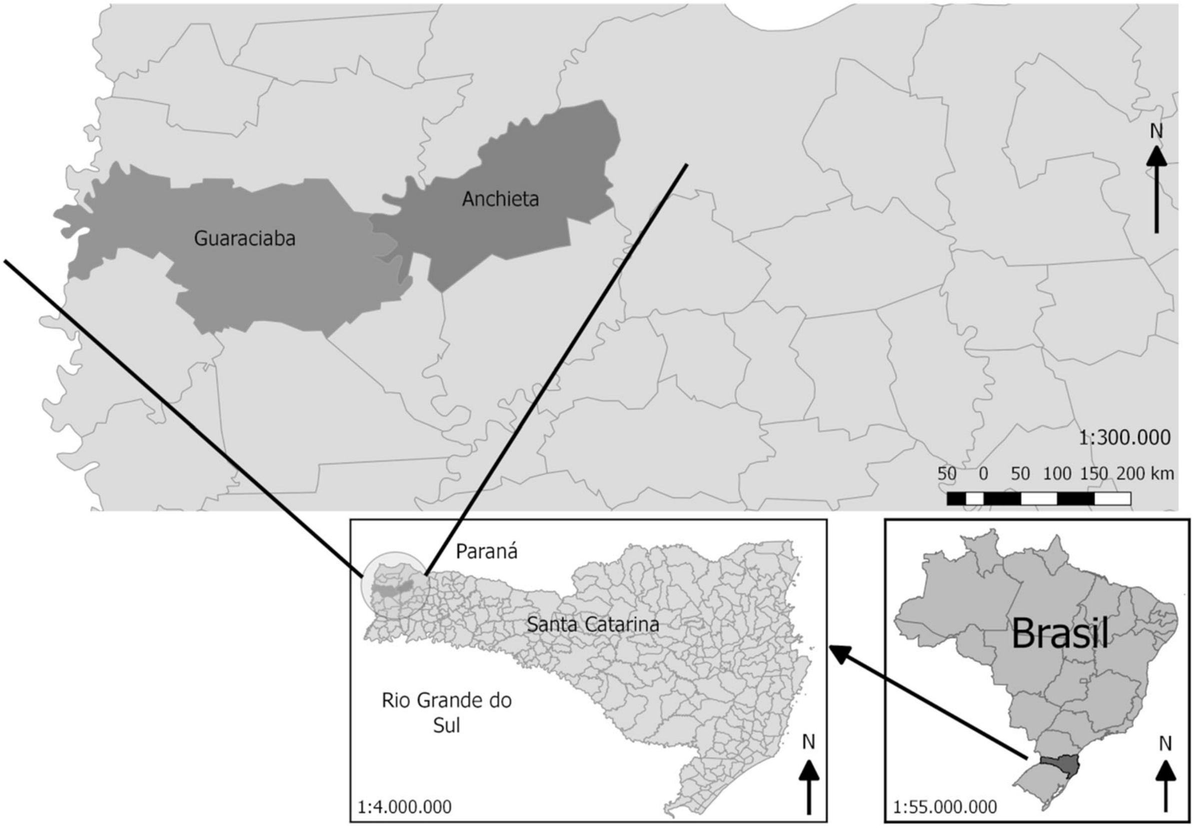

Fig. 1 Location of far western Santa Catarina, in southern Brazil

performed on two 30 g-samples of peeled grains (mean of 1121 grains/sample) with a Rice Grain Scanner (Marschalek et al. 2017).

Data analysis

Morphological characterization data were analyzed by using descriptive statistics (absolute and relative frequencies) with non-parametric tests (Chi square) conducted at a significance level of 5%. Euclidian distances were calculated for the analysis of diversity, based on a matrix containing the ordinal and quantitative variables. The correlation between the variables was verified as a criterion for the use of the corresponding characters in the Euclidean distance calculation, based upon the PAST 3.04 program (Hammer et al. 2001). Those variables that presented high correlation (> 0.8) were eliminated from further analysis along with those with the lowest overall diversity. The Unweighted Pair Group Method with Arithmetic Mean (UPGMA) was used to identify groups and for a graphical representation of local varietal diversity. A principal component analysis (PCA) was performed based upon a sample covariance matrix of standardized quantitative data, to clarify the interrelationships among variables as related to the distribution and grouping of local rice varieties. Two- and three-dimensional representations of the local varieties were created from the principal components extracted. Multivariate analyses were performed in R, by using the functions of the vegan packages (Oksanen et al. 2007), stats, graphics and base (R Core Team 2016).

Morphological groups (MGs) were described based on the following morphological characteristics of grain: color and pubescence of palea and lemma, presence of edge, shape and color of the whole grain.

The identification of groups of *O. sativa* L. was carried out as described by Chang and Bardenas (1965). Thus, phenotypes with short, round grains, with dense and long hairs in the palea and lemma, with or without a long edge belong to Group Japonica, whereas phenotypes with fine grains, with short hairs in the palea and lemma, and no edge, most often belong to Group Indica.

Results

Phenotypic characterization

The phenotypic characterization showed that the dryland rice varieties conserved on farm in FWSC have significant diversity for qualitative variables both among and within varieties, as documented by through character means, standard deviations and coefficients of variation for the quantitative morphological characteristics (Table 1), and supported by variation evidenced in the qualitative descriptors.

The most common vegetative characteristics were green leaf color (46%); leaves with little or no pubescence (29%); erect leaf flags (40%); pale green culm color (68%); nodes with weak or no anthocyanin staining (79%); sheaths with purple streaks (41%); and tillers with intermediate divergence angles (38%).

The average number of tillers was 5.95 per plant, with a minimum of 2.95 and maximum of 14.80. Regarding the lodging of plants, 27% of the varieties did not fall down, 27% presented up to 25% of the area with fallen plants, 16% up to 50% of the area, 16% up to 75%, and 14% had more than 75% of the area covered with fallen plants.

The populations presented a wide amplitude for the averages of plant height (from 50.6 to 150.9 cm); eight varieties had short culms (71–90 cm), 38 had culms from short to intermediate (91–105 cm), 13 were intermediates (106–120 cm), one was long intermediate (121–140 cm) and one was long (141–155 cm). The Pearson correlation coefficient between length and lodging was 0.70, indicating a linear association between the variables and an increase of the lodging percentage with the extent of plant height.

The most common reproductive character states were white stigmata (56%), semi-erect and scattered panicles (29%) and panicle excision from full to medium (62%). Additionally, for these characters, populations presented notable variation among individual plants within the same variety.

For the variable, number of panicles per plant, the average was 4.53, and the minimum and maximum values were 2.4 and 9.5, respectively. The average panicle length was 24.4 cm, with a minimum of 18.9 and a maximum of 27.3 cm. For six populations, the husking process was considered easy, intermediate for two, intermediate to difficult for 53 and difficult for remaining two populations. The degree of difficulty of husking also evidences high diversity levels among plants of the same variety.

With regard to grain characteristics, 79.4% of the varieties presented fertile spikelets, glumes of straw staining, 4.76% straw and gold, 9.52% gold and 6.35% brown. The pubescence of the palea and lemma was

Table 1 Mean, standard deviation and coefficient of variation (CV %) of ten quantitative morphological characteristics, evaluated in three commercial cultivars and sixty upland rice landraces of far west of the state of Santa Catarina

Morphological characteristics	Mean	Range	SD	CV (%)
Thickness of culm (mm)*	3.46	2.22–4.00	0.30	8.52
Length of culm (cm)*	99.85	50.60–150.90	13.58	13.60
Number of tillers (score)*	5.95	2.95–14.80	2.16	36.29
Number of panicles (score)*	4.54	2.40–9.50	1.15	25.43
Length of panicle (cm)*	24.45	18.95–27.30	1.56	6.40
Length of awn (mm)*	2.37	0.73–5.23	1.16	48.90
Length of whole grain (mm)**	7.00	5.30–7.65	0.48	6.88
Width of whole grain (mm)**	2.59	2.05–2.87	0.16	6.23
Thickness of whole grain (mm)**	1.78	1.59–1.91	0.09	5.00
Weight of 1000 grains (g)**	24.19	16.82–11.16	4.05	16.73

*Mean of two replicates, estimated from 20 plants of the plot area

**Mean of two replicates, estimated in samples of 30 g of peeled grains (mean 1121 grains/sample) also variable, since 38% of the varieties were glabrous, 6.35% had a poor pubescence, 12.7% average pubescence and 28.6% strong pubescence.

Among the 63 varieties analyzed, 19 presented awn with an average length of 2.5 mm, varying from 0.7 to 5 mm. There is significant variation in the development of this structure; plants of the same variety can have both fully awned and awnless caryopses, as well as both fully awned and awnless panicles.

For the color of whole grain, 76% of the varieties presented light brown grains and 24% red grains. The grain size analysis showed an average length of whole grain of 7.0 mm, varying from 5.3 to 7.6 mm; average width of 2.6 mm, in the range of 2.0 to 2.9 mm and; average thickness of 1.8 mm, varying from 1.6 to 1.9 mm (Table 1). From the total grain length/width ratio and classification proposed by MAPA (Brazil 1997), 54% of the varieties have medium-elongated grains, 43% elongated grains and 3% highly-elongated grains; no variety had short-rounded grains. When applying the commercial classes of rice proposed by Castro et al. (1999), 48% of the evaluated varieties have long-fine grains, 47% long grains and 5% average grains. The average weight of 1000 grains was 24.2 g, with a minimum of 16.8 g and a maximum of 44.2 g.

The correlation analysis between grain characteristics showed a moderate positive correlation between the presence of awns and the color of the palea and lemma ($r = 0.50$; $p < 0.001$), indicating that varieties with darker palea and lemma usually have awns. Another moderate positive correlation was found between the pubescence of the palea and lemma and the color of the whole grain ($r = 0.64$; $p < 0.001$), indicating that varieties with denser hairs are also more often the ones with darker pericarps.

The variables, pubescence of the palea and lemma and whole grain shape are negatively and moderately associated ($r = -0.60$; $p < 0.001$). In this case, varieties with the smallest grain are most often hairy. A moderate negative correlation was also observed between the color of the whole grain and the whole grain shape ($r = -0.42$; $p < 0.001$), indicating that the smallest grains also most often present a dark pericarp.

Morphological groups

Morphological analyses indicated that 24 populations have characteristics of Group Indica, four present characteristics of Group Japonica, and 35 varieties included a mixture of plants, sometimes with characteristics of Indica and others of Japonica (Table 2).

Based on the morphological characteristics of the color and pubescence of the palea and lemma, presence of awn, and the shape and color of whole grain, 21 morphological groups (MGs) were described (Table 3). The most common MG is comprised of 14 landraces and two controls (BRS Monarca and BRS Sertaneja); they are identified by caryopsis straw, glabrous, without awn, and elongated, light brown grain. The second most frequent MG, with eight local varieties, was characterized by caryopsis straw, awnless, pubescent palea and lemma, and medium-elongated, red grain. The third MG with seven landraces differs from the latter only by its light brown grain. Among the 21 MGs, 11 were represented by only a single variety, suggesting the presence of considerable morphological diversity among these landraces.

The mapping of MGs (Fig. 2) shows randomness in the geographic distribution of these characteristics, since the most common groups (MGs 13, 9 and 8) are scattered among different communities in the two studied municipalities.

Diversity analysis

Among 35 descriptors, four did not vary (atrial color, ligule color, color of sterile lemmas and apical format) and were excluded from the analysis. The cluster analysis shows the isolation of four populations and the formation of four large groups.

Most of the analyzed descriptors present a great variation of states among the plants of the same accession. The coefficient of variation was calculated for the 27 characteristics used in the morphological descriptors. The populations presented on average approximately 16 characteristics with CV equal to zero, 9 characteristics with CV between 0 and 50% and 2 with CV above 50%. Such variation is reflected in the relatively low degree of dissociation among the groups generated in the cluster analysis (Fig. 3). The presence of plants with divergent characteristics within the same population made it difficult for the separation of a larger number of groups. Moreover,

Table 2 Classification of the landraces of dryland rice conserved in the FWSC, for the Indica and Japonica Groups

Group	Number	Representative landraces
Indica	24	215SN; 1084SN; 725Alto; 2316SN; 76Agulhinha; 396SN; 2503Crioulo; 324SN; 2073Amarelão; 2069SN; 2705Branquinho; 725Baixo; 2452SN; 2504SN; 648Amarelo; T1Monarca; T2Sertaneja; 2231Agulhinha; 2108Amarelão; 2184Adriano; 2385Amarelinho; 2567Amarelo; 2544Amarelão; T3Dourada.
Japonica	4	2329Preto; 2710Vermelho; 1105Preto; 650Preto.
Plants within the variety with Indica and Japonica characteristics	35	720SN; 2071SN; 2329Amarelão; 2174Amarelão; 242SN; 694MatoGrosso; 934Piriquito; 1158Piriquito; 1105BrancoDirceu; 2319Perin; 439Amarelinho; 636Preto; 650Branco; 965SN; 716Antigo; 71SN; 959Sauthier; 2474Agulhão; 100SN; 2534Branco; 2092Piriquitinho; 2433Ribas; 2433Fonsceca; 2433Agulhinha; 2590Amarelão; 71Branco; 650Marrom; 2529SN; 2319Crestani; 967Colonial; 648Amarelo2; 2109PalhaRoxa; 2527Agulhinha; 2015SN; 2109Agulhinha.

this fact indicates that even in this predominantly autogamous species, these rice landraces present possibilities of natural crossing (Sahadevan and Namboodiri 1963) and thus selectable variability.

Together with the control cultivar, BRS Serra Dourada (T3Dourada), three local populations were isolated by cluster analysis; they are 2109Agulhinha, 1158Piriquito and 967Colonial. The control cultivar BRS Serra Dourada and the accession 2109Agulhinha were the populations with the shortest plants (74.9 and 50.6 cm, respectively) and very elongated grains. The 1158Piriquito accession could be distinguished by its short panicle length (18.9 cm) and long edge (5.2 mm), while the 967Colonial accession was distinctive because it had the most tillers (14.9 tiller/-plant) of all the accessions evaluated.

Group I grouped three accessions (2071SN, 2329Amarelão and 2174Amarelão) due to similarities in grain characteristics (color, shape, length, thickness and weight); accessions 2071SN and 2329Amarelão are in MG15.

Group II grouped 41 landraces (648Amarelo2, 720SN, 934Piriquito, 694MatoGrosso, 1084SN, 215SN, 959Sauthier, 242SN, 2109PalhaRoxa, 2174Agulhão, 1033SN, 71SN, 105BrancoDirceu, 2385Amarelinho, 2567Amarelo, 2544Amarelão, 2015SN, 725Baixo, 324SN, 2527Agulhinha, 2534Branco, 725Alto, 648Amarelo, 439Amarelinho, 636Preto, 650Branco, 396SN, 2184Adriano, 965sn, 716Antigo, 2108Amarelão, 2069SN, 2316SN, 2073Amarelão, 2504SN, 76Agulhinha, 2319Crestani, 2231Agulhinha, 2705Branquinho, 2503Crioulo, and 2452SN) and the other two control cultivars, BRS Monarca and BRS Sertaneja. This group was the most diverse, with intermediate characteristics in relation to the other groups. Their grains presented a medium-elongated or elongated shape, brown or red pericarps and, in a general way, fit within Group Indica.

Group III included four accessions (2329Preto, 650Preto, 2710Vermelho, and 1105Preto) that presented more rustic grains, having caryopses with palea and lemma pubescent, whole grains of red color and medium-elongated format, of a shorter ($\mu = 6.4$ mm) and thicker ($\mu = 2.8$ mm) shape. All accessions belonging to group III were included in MG 21.

Group IV grouped nine local accesses (2433Ribas, 2433Agulhinha, 2590Amarelão, 2092Piriquitinho, 2433Fonseca, 2319Perin, 2529SN, 71Branco, and 650Marrom) that produced smaller, dark grains. These varieties were classified as belonging to MG 9, except accession 2319Perin, belonging to MG 2. They also exhibited the highest degree of lodging, which may help differentiate them from the accessions of group III.

The representation of the first two principal components (PC) (Fig. 4), extracted from the analysis of 12 quantitative variables, shows a grouping structure similar to that pointed out in the cluster analysis. PC 1, 2 and 3 together explain 59% of the phenotypic variation. The first PC explains about 24% of the total variation. In this axis, the most explanatory variables are culm thickness, panicle length, weight of 1000 grains and grain thickness. The second PC explains about 21% of the total variation, and the most of

Table 3 Morphological groups based on morphological characteristics of grains and their respective representative varieties of dryland rice from far western Santa Catarina

MG	CPL	PA	PG	GF	CWG	N	Landraces*
1	Straw	Yes	Yes	Long-half	Brown	5	1158Piriquito; 934Piriquito; 242SN; 1105BrancoDirceu; 694MatoGrosso
2	Straw	Yes	Yes	Long-half	Red	1	2319Perin
3	Straw	Yes	Yes	Long	Red	1	720SN
4	Straw	Yes	Yes	Very-long	Brown	1	2109Agulhinha
5	Straw	Yes	No	Long-half	Brown	2	439Amarelinho; 636Preto
6	Straw	Yes	No	Long	Brown	1	2071SN
7	Straw	Yes	No	Long-half	Brown	1	650Branco
8	Straw	No	Yes	Long-half	Brown	7	965SN; 716Antigo; 71SN; 959Sauthier; 2474Agulhão; 1033SN; 2534Branco
9	Straw	No	Yes	Long-half	Red	8	2092Piriquitinho; 71Branco; 650Marrom; 2529SN; 2433Ribas; 2433Fonseca; 2433Agulhinha; 2590Amarelão
10	Straw	No	Yes	Long	Brown	4	2316SN; 215SN; 1084SN; 725Alto
11	Straw	No	No	Long-half	Brown	1	2319Crestani
12	Straw	No	No	Long-half	Red	1	967Colonial
13	Straw	No	No	Long	Brown	16	396SN; 2184Adriano; 2108Amarelão; 2069SN; 2073Amarelão; 2504SN; 76Agulhinha; 2231Agulhinha; 2503Crioulo; 2705Branquinho; 2452SN; 324SN; 725Baixo; 648Amarelo2; 2231Agulhinha; BRS Monarca; BRS Sertaneja
14	Straw	No	No	Very-long	Brown	1	BRS Serra Dourada
15	Golden	Yes	No	Long	Brown	2	2329Amarelão; 2174Amarelão
16	Golden	No	Yes	Long-half	Brown	1	648Amarelo
17	Golden	No	No	Long	Brown	3	2385Amarelinho; 2567Amarelo; 2544Amarelão
18	Straw and Golden	Yes	Yes	Long-half	Brown	1	2109PalhaRoxa
19	Straw and Golden	No	Yes	Long-half	Brown	1	2527Agulhinha
20	Straw and Golden	No	No	Long-half	Brown	1	2015SN
21	Brown	Yes	Yes	Long-half	Red	4	2329Preto; 2710Vermelho; 650Preto; 1105Preto

*The number preceding the variety name identifies the farmer holding. *MG* morphological group, *CPL* color of palea and lemma, *PA* presence of awn, *PG* Pubescence of the palea and lemma, *GF* whole grain format, *CWG* color of whole grain, N: number of varieties belonging to the morphological group

explanatory variables of this axis are the degree of lodging, and the length and width of grains. The third PC accounts for about 14% of the variation, the most explanatory variables being the plant cycle, the difficulty of the husking process and culm length.

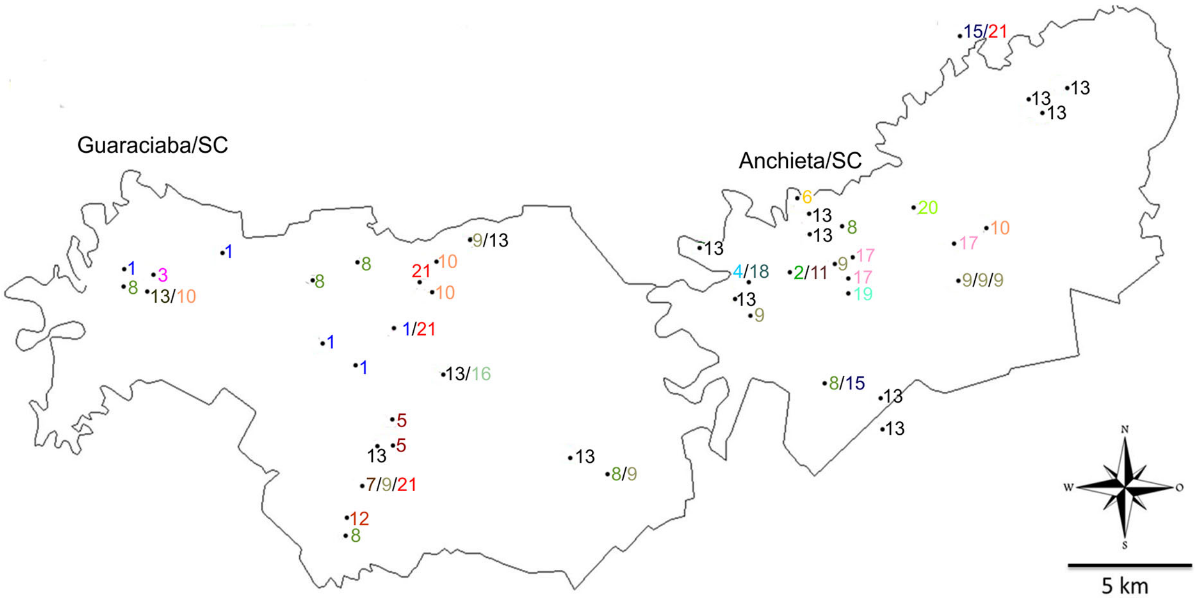

Fig. 2 Geographic distribution of the identified morphological groups of local varieties of dryland rice from far western Santa Catarina, based on caryopsis and grain descriptors. Points with more than one number mean farmers who conserve more than one landrace. Cultivars provided by EMBRAPA do not appear on the map. Morphological group 14 (MG 14) comprises only commercial BRS Serra Dourada cultivar and, therefore, is not represented in the distribution map

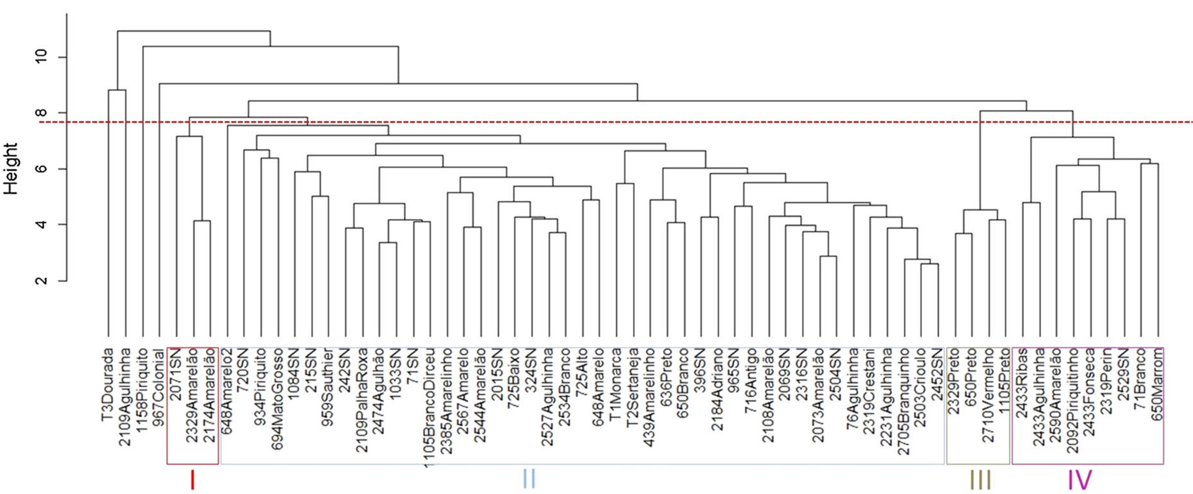

Fig. 3 Grouping of landraces of dryland rice conserved in the far western Santa Catarina and three commercial cultivars of the CNPAF/EMBRAPA, generated from Euclidians distance with UPGMA clustering. Cophenetic correlation = 0.82

Discussion

Alvarez et al. (2012) classified rice varieties into traditional, modern and intermediate categories according to the type of plant. The traditional type has a great size, with long and decumbent leaves, long vitreous grains, low tillering capacity, good resistance to diseases of secondary importance, stable production and less lodging in fertile soils. These characteristics can be found in the varieties of group III. In contrast, modern varieties are smaller with, long, fine grains, short and erect leaves, strong culms, high tillering and grain yield, and little lodging. The intermediate varieties result from hybridization between traditional

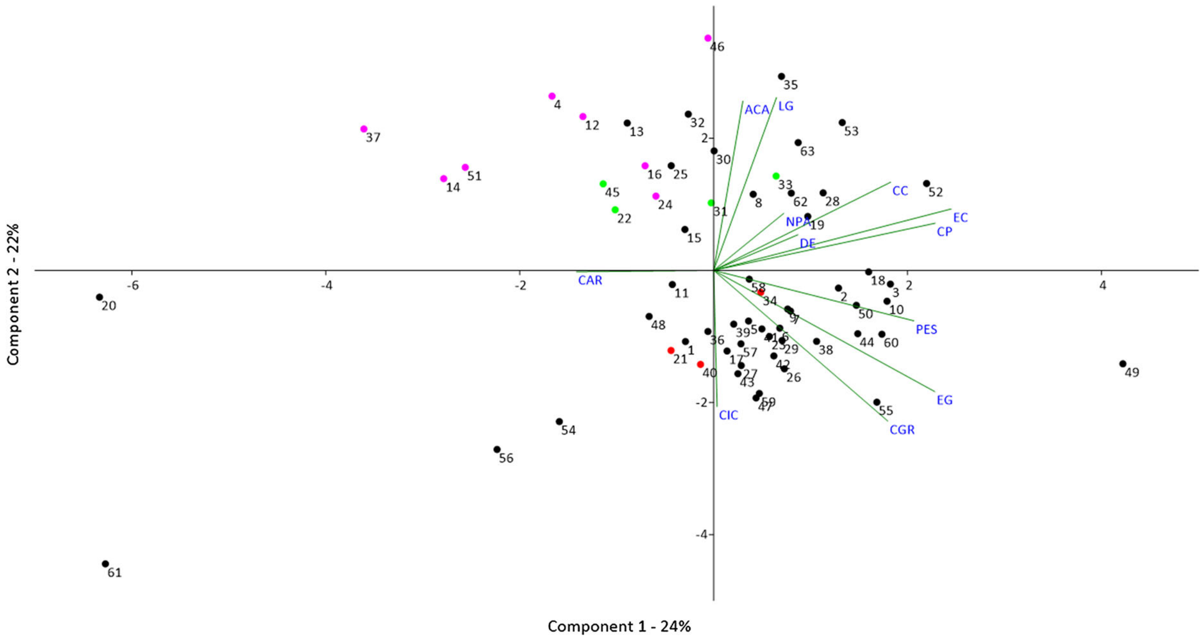

Fig. 4 Representation of the first two main components explaining 45.28% of the total variation, extracted from the analysis of 12 morphological, phenological and agronomic variables of 60 landraces of dryland rice conserved in the far western Santa Catarina and three commercial cultivars. Roman numerals (I, II, III and IV) Inticate the approximate positions of the groups visualized in the cluster analysis. Colored dots represent the same dendrogram groups: group 1 red; group 2 black; group 3 green; group 4 pink. Roman numerals represent the following varieties: *1* 76Agulhinha; *2* 965SN; *3* 215SN; *4* 2092Piriquitinho; *5* 1084SN; *6* 2385Amarelinho; *7* 716Antigo; *8* 2527Agulhinha; *9* 2567Amarelo; *10* 396SN; *11* 934Piriquito; *12* 2433Ribas; *13* 2433Fonseca; *14* 2433Agulhinha; *15* 2015SN; *16* 2590Amarelão; *17* 2503Crioulo; *18* 324SN; *19* 439Amarelinho; *20* 1158Piriquito; *21* 2329Amarelão; *22* 2329Preto; *23* 2073Amarelão; *24* 71Branco; *25* 71SN; *26* 2069SN; *27* 2705Branquinho; *28* 959Sauthier; *29* 636Preto; *30* 242SN; *31* 2710Vermelho; *32* 1105BrancoDirceu *33* 1105Preto; *34* 2174Amarelão; *35* 2474Agulhão; *36* 2319Crestani; *37* 2319Perin; *38* 725Alto; *39* 725Baixo; *40* 2071SN; *41* 2544Amarelão; *42* 2316SN; *43* 2452SN; *44* 650Branco; *45* 650Preto; *46* 650Marrom; *47* 2504SN; *48* 648Amarelo; *49* 648Amarelo2; *50* 720SN; *51* 2529SN; *52* 694MatoGrosso; *53* 1033SN; *54* BRSMonarca; *55* BRSSertaneja; *56* BRSMonarca; *57* 2231Agulhinha; *58* 2534Branco; *59* 2108Amarelão; *60* 2184Adriano; *61* 2109Agulhinha; *62* 2109PalhaRoxa; *63* 967Colonial

and modern varieties, aiming to reduce height and improve grain quality (Alvarez et al. 2012). The varieties of groups I, II and IV presented variant characteristics between the modern and intermediate types.

The cultivars developed by CNPAF/EMBRAPA had very similar characteristics with long-fine grains, the Brazilian consumer market preference. These cultivars were used in function of the absence of dryland varieties indicated for southern Brazil. The objective of these cultivars in the present study was to allow the evaluation of their eco-physiological behavior and not to situate them within a framework of diversity, since they are not part of the established gene pool in the study region.

The presence of awns in some populations (MGs 1, 2, 3, 4, 5, 6, 7, 15, 18 and 21) is indicative of the least domestication effort, since the reduction or exclusion of the awns was one of the changes caused by the rice domestication syndrome (Sang and Ge 2007, Holland 2014). Their presence also is indicative of the absence of formal genetic improvement, since breeders often seek to select genotypes without awns or with short awns short to obtain improvements in post-harvest handling (Sato et al. 1996).

Regional consumption preferences drive food markets and are of great importance in any rice-breeding strategy. The Brazilian market has preference for long-fine grains, which expand and remain loose and soft after cooking (Pereira and Rangel 2001). Long-fine grains are present in all strata of the core collection maintained by Brazil's primary genebank (CNPAF/EMBRAPA), including traditional varieties, inbred lines and cultivars (both national and introduced) for irrigated, dry or flexible cultivation (Brondani et al. 2006).

Although there may be a national preference for long-fine grains, they have the lowest protein content of the major rice grain types (Araújo et al. 2003; Areias et al. 2006). The current search for healthier, nutrient-rich foods serves as an incentive for rice-breeding programs that prioritize selection strategies for more nutritious grain (Wickert et al. 2014). When premium prices are offered for more nutritious products, this also encourages rice growers to seek quality seeds of special types, such as the "cateto" type, black and red.

In many localities, including southern Brazil, red rice is considered an invasive weed in white rice paddies, engendering strict controls (Gealy et al. 2003). On the other hand, in northeastern Brazil, red grains are traditionally included in the diet (Almeida 2004). Comparisons of agronomic and biochemical attributes between red and white varieties have varied in different geographic evaluations. In the state of Piauí, white rice varieties were more productive and showed higher levels of amylose, while red varieties had higher levels of iron and zinc (Pereira et al. 2009). In Rio de Janeiro state, red types had higher productivity of viable panicles and did not differ from white cultivars in their percentage of fertile spikelets per panicle or in grain yield, revealing their agronomic potential for dryland cultivation (Menezes et al. 2011).

Recently, in the southern Brazil, the Agricultural Research and Rural Extension Company of Santa Catarina—EPAGRI has released SCS 119 Rubi, a red-grained cultivar for irrigated conditions. It was selected from red rice populations that were invading irrigated plantations of conventional white varieties (Wickert et al. 2014), with the goal of encouraging the production and consumption of this special type of rice.

Among the local varieties from FWSC, 15 show reddish pericarp and could be used as initial populations in breeding programs. These populations average 104 cm tall (range 81–131 cm), a medium degree lodging of 45% (range 6–100%), husking from intermediate to difficult, and a mean number of tillers of 6.82 (range 2.95–14.90) and of panicles of 4.72 (range of 3.05–9.50). It seems clear that their diversity is selectable for useful traits among these red-grained landraces.

Most of the traits we evaluated presented significant variation both within and among populations. This type of evaluation plays a fundamental role in the identification of divergent varieties, since genetic variability is the basis of evolutionary processes and genetic improvement, and it is essential for selection pressures in the agricultural ecosystem to be effective (Jennings et al. 1982).

The evidences indicate that the diversity found within the populations occurs as a consequence of the sociocultural practices and variety management. Field cultivation without spatial isolation and inadequate cleaning of equipment used for threshing are two examples of processes that can lead to inadvertent seed mixtures. In addition, intentional gifts and exchanges of seeds between farmers can also bring together formerly distinctive landraces, which, when grown in close proximity, can exchange alleles and form new gene combinations. Considering that most of the farmers keeps only one variety and that their fields of production are located at long distances from each other, it is assumed that the diversity found within the landraces, in advance, is mainly derived from the seed mixture. From the mixture (intentional or not) and the planting of these seeds as belonging to the same population, then the gene flow between the different genotypes is facilitated. However, no gene flow among the varieties was evaluated by this research.

The present work is a first collaborative effort between farmers and breeders in FWSC that can contribute to the selection and development of rice varieties with greater adaptation to local conditions and greater acceptance by consumers as they search for types of rice best suited for the typical dishes of the region. To work toward these goals, two action plans for participatory genetic improvement of dryland rice conserved in the FWSC have been suggested. The first plan is based on varieties that can be selected for (1) reduction of grain length looking for "cateto" type; (2) reduction and/or elimination of awns to facilitate harvest and processing; (3) reduction of the height of the culm to reduce lodging damage; and (4) composition of populations with the same cycle and morphological characteristics of grain to increase the diversity within farm, add economic value and facilitate cultivation practices and harvesting. Among the local landraces, varieties with dark grains were the ones that presented the lowest percentages of lodging. From these types, individual-plant selection, followed by progeny testing focused on the development of blends, would be feasible.

For the second plan, we analyzed the passport data of the varieties collected by Pinto et al. (2018) and listed the varieties conserved for at least 10 years in the region. Of those with the least lodging, we focused on those varieties with the heaviest and longest grains. The cumulative duration of cultivation by the same family in the region is relevant here, because it is an attribute commonly associated with the adaptation of genotypes to local agroecosystems (Zeven 1998; Ogliari et al. 2013). Based on those criteria, entries 76Agulhinha, 965SN, 2503Crioulo, 2069SN, 2705Branquinho, 636Preto, 725Baixo, 2316SN, 2452SN, 650Branco, 648Amarelo, and 2534Branco are of special interest. Also, considering the average number of panicles per plant, 396SN, 2433Ribas, 439Amarelinho, 2073Amarelão, 959Sauthier, 650Marrom, 2504SN, 2231Agulhinha, 2184Adriano, and 967Colonial might also be included in the first stages of field evaluation to verify their adaptative behavior and agronomic and industrial potential. Populations with high genetic variation within and highlighted genetic potential could be forwarded for an integrated and participatory approach in genetic breeding, conservation and use of rice landraces. In this way, the adding economic value to local genetic resources through tailor-made approaches for endogenous development would be a key element not only for the improvement and conservation of diversity, but also for the preservation of traditions and costumes in this region of the country.

Brazil is by no means the "center of origin" of *O. sativa* L., but it can be considered as a potential "center of diversity." The rice populations in FWSC differ from those in Asia, because both abiotic (soil and climate characteristics, topography, elevation) and biotic (pathogenic and endophytic microorganisms and pests) factors also are unique, and in this way, southern Brazil may also contribute with unique diversity to the primary gene pool.

According to the scientific literature, centers of diversity are geographic regions where the domestication and diversification of a species still occur, either through natural processes or through human action, being areas of accumulation of diversity of certain species (Hawkes 1983; Harlan 1992; Clement 1999). In fact, a unique feature of FWSC is the recent indication of this region as a microcenter of diversity for the genus *Zea*, due to the in situ/on farm conservation of a high number (1513) of local maize populations (common, popcorn, floury and sweet) associated with different uses (Costa et al. 2016), in addition to the presence of *Zea luxurians* (Durieu et Asch.) R.M. Bird (a wild relative of maize) undergoing its own process of domestication (De Almeida Silva et al. 2015). Although the richness and abundance of local dryland rice varieties in this region are apparently more modest as compared to maize, the diversity of rice varieties conserved in situ/on farm is a major aspect of food security for families living in FWSC (Pinto et al. 2018).

Not only does the FWSC stand out because it is a region with a high diversity of maize or rice landraces, but, notably, of both crops, suggesting that this region is a microcenter of crop diversity. As defined by Brazilian legislation (Brasil 2008), microcenters of crop diversity refer to small geographical areas that maintain a high level of genetic and/or morphological diversity of species cultivated in situ. As such, these areas are priorities for measures to rescue and conserve agrobiodiversity. In view of the devastating scenario of genetic erosion for various local crops in this region over recent years (Pinto 2017), the formulation of agricultural policies, based on the designation of FWSC as a Zone of Agrobiodiversity Conservation, is becoming urgent.

Acknowledgements This is a collaborative work involving family farmers in far western Santa Catarina with the support of students of the Federal University of Santa Catarina (UFSC) and partnership organizations (Secretary of Education and Secretary of Health of Anchieta and Guaraciaba, Parish of Santa Lucia of Anchieta, Small-Scale Farmers Movement/MPA, Union of Workers of Family Farming/SINTRAF of Anchieta, Association of Small Growers of Organic Maize Landrace and Derivatives/ASSO, Central Development Association of Microbasins of Guaraciaba, Integrated Company of Agricultural Development of Santa Catarina/CIDASC, and the Experimental Station of the Company of Agricultural Research and Rural Extension of Santa Catarina/EPAGRI from Itajaí/SC). Wander Luís Marques collaborated in the creation of the geographical location map of the FWSC. Coordination for the Improvement of Higher Education Personnel/Capes provided a scholarship to Tassiane Terezinha Pinto.

Compliance with ethical standards

Conflict of interest No known or potential conflicts of interest exist for any author.

References

Abadie T et al (2005) Construção de uma coleção nuclear de arroz para o Brasil. Pesquisa Agropecuária Brasileira 40(2):129–136. https://doi.org/10.1590/S0100-204X2005000200005

Almeida JAP (2004) O arroz vermelho cultivado no Brasil. Editora Embrapa, Teresina

Alvarez F, De Cassia R, Crusciol C, Alexandre C, Stephan Nascente A (2012) Análise de crescimento e produtividade de cultivares de arroz de terras altas dos tipos tradicional, intermediário e moderno. Pesquisa Agropecuária Tropical 42(4):397–406. https://doi.org/10.1590/S1983-40632012000400008

Araújo ES, Souza SR, Fernandes MS (2003) Características morfológicas e moleculares e acúmulo de proteína em grãos de variedades de arroz do Maranhão. Pesquisa Agropecuária Brasileira 38(11):1281–1288. https://doi.org/10.1590/S0100-204X2003001100005

Areias RGBM, Paiva DM, Souza SR, Fernandes MS (2006) Similaridade genética de variedades crioulas de arroz, em função da morfologia, marcadores RAPD e acúmulo de proteína nos grãos. Bragantia 65(1):19–28. https://doi.org/10.1590/S0006-87052006000100004

Barbosa-Filho MP, Yamada T (2002) Upland rice production in Brazil. Better Crops Int 16:43–47

Bioversity International, IRRI and WARDA (2007) Descriptors for wild and cultivated rice (*Oryza* spp.). https://www.bioversityinternational.org/e-library/publications/detail/descriptors-for-wild-and-cultivated-rice-oryza-spp/ Accessed 20 Oct 2018

Brasil (1997) Descritores mínimos para a cultura do arroz. Serviço Nacional de Proteção de cultivares, Diário Oficial da União. http://www.apps.agr.br/upload/ax4_1102200842996900_decreto2366-arroz.pdf Accessed 05 May 2018

Brasil (2008) Ministério da Agricultura, Pecuária e Abastecimento. Tratado Internacional sobre Recursos Fitogenéticos para Alimentação e Agricultura. Brasília. http://www.planalto.gov.br/ccivil_03/_Ato2007-2010/2008/Decreto/D6476.htm Accessed 05 May 2018

Brasil (2018) Brazilian rice: Production Profile. http://brazilianrice.com.br/en/sobre-o-brasil/ Accessed 06 May 2018

Brondani C, Borba TCO, Rangel PHN, Brondani RPV (2006) Determination of genetic variability of traditional varieties of Brazilian rice using microsatellite markers. Genet Mol Biol 29(4):676–684. https://doi.org/10.1590/S1415-47572006000400017

Chang T, Bardenas EA (1965) The morphology and varietal characteristics of the rice plant. The International Rice Research Institute, Los Baños, Philippines

Clement CR (1999) 1492 and the loss of Amazonian crop genetic resources. II. Crop biogeography at contact. Econ Bot 53(188):203–216. https://doi.org/10.1007/BF02866498

Costa FM, De Almeida Silva NC, Ogliari JB (2016) Maize diversity in southern Brazil: indication of a microcenter of *Zea mays* L. Genet Resour Crop Evol 64(4):681–700. https://doi.org/10.1007/s10722-016-0391-2

Da Silva ED, Montalván R, Ando A (1999) Genealogia dos cultivares brasileiros de arroz-de-sequeiro. Bragantia 58(2):281–286. https://doi.org/10.1590/S0006-87051999000200007

De Almeida Silva NC, Vidal R, Costa FM, Vaio M, Ogliari JB (2015) Presence of *Zea luxurians* (Durieu and Ascherson) Bird in southern Brazil: implications for the conservation of wild relatives of maize. PLoS ONE 10(10):1–16. https://doi.org/10.1371/journal.pone.0139034

Embrapa (2013) Catálogo de Cultivares de Arroz 2014. https://www.embrapa.br/busca-de-publicacoes/-/publicacao/985671/catalogo-de-cultivares-de-arroz-2014-2015 Accessed 20 Sept 2015

Fageria NK, Wander AE, Silva SC (2014) Rice (*Oryza sativa*) cultivation in Brazil. Indian J Agron 59(3):350–358

FAO (2004) Rice around the world—Brazil. http://www.fao.org/rice2004/en/p1.htm Accessed 06 May 2018

Gealy DR, Mitten DH, Rutger JN (2003) Gene flow between red rice (*Oryza sativa*) and herbicide-resistant rice (*O. sativa*): implications for weed management. Weed Technol 17(3):627–645. https://doi.org/10.1614/WT02-100

Gonçalves GMB et al (2013) Caracterização e avaliação de variedades de arroz de sequeiro conservadas por agricultores do Oeste de Santa Catarina. Revista Agropecuária Catarinense 26:63–69

Hammer Ø, Harper DAT, Ryan PD (2001) PAST: Paleontological Statistics Software Package for education and data analysis. Palaeontol Electron 4(1):1–9

Harlan JR (1992) Crops and man, 2nd edn. American Society of Agronomy/Crop Science Society of America, Madison

Hawkes JG (1983) The diversity of crop plants. Harvard University Press, Cambridge

Holland JB (2014) Breeding: plants, modern. Encycl Agric Food Syst 2:187–200

Jennings PR, Coffman WR, Kauffman HE (1982) Mejoramiento de arroz. Centro Internacional de Agricultura Tropical, Cali, Colombia

Kato Y, Okami M, Katsura K (2009) Yield potential and water use efficiency of aerobic rice (*Oryza sativa* L.) in Japan. Field Crops Res 113(3):328–334. https://doi.org/10.1016/j.fcr.2009.06.010

Marschalek R et al (2017) Image-rice grain scanner: a three-dimensional fully automated assessment of grain size and quality traits. Crop Breed Appl Biotechnol 17:89–97. https://doi.org/10.1590/1984-70332017v17n1s15

Menezes BRS, Moreira LB, Lopes HM, Pereira MB (2011) Caracterização morfoagronômica em arroz vermelho e arroz de sequeiro. Pesquisa Agropecuária Tropical 41(4):490–499. https://doi.org/10.5216/pat.v41i4.11876

Ogliari JB, Kist V, Canci A (2013) The participatory genetic enhancement of a local maize variety in Brazil. In: de Boef W, Subedi A, Peroni N, Thijssen M, O'Keeffe E (eds) Community biodiversity management. Promoting resilience and the conservation of plant genetic resources. Routledge, Abingdon, pp 265–271

Oksanen J et al (2007) The vegan package—community ecology package. https://cran.r-project.org/web/packages/vegan/vegan.pdf Accessed 05 May 2018

Padrão G (2018) Desempenho da produção vegetal—Arroz. In: Epagri/CEPA (org). Síntese Anual da Agricultura de Santa Catarina 2014–2015. http://docweb.epagri.sc.gov.br/

website_cepa/publicacoes/Sintese-Anual-da-Agricultura-SC_2016_17.pdf. Accessed 20 Oct 2018
Pereira JA, Rangel PHN (2001) Produtividade e qualidade de grãos de arroz irrigado no Piauí. Ciência e Agrotecnologia 25:569–575
Pereira JA, Bassinello PZ, Cutrim VDA, Ribeiro VQ (2009) Comparison among agronomic, cooking and nutritional characteristics in white and red rice varieties. Rev Caatinga 22:243–248
Pinto TT (2017) A cultura do arroz de sequeiro no Extremo Oeste de Santa Catarina: diversidade, conhecimentos associados e riscos de erosão genética de variedades locais conservadas pela agricultura familiar. Tese (Doutorado) Universidade Federal de Santa Catarina, p 175
Pinto TT, Ogliari JB, Souza R, Gonçalves GMB (2018) O arroz de sequeiro e a segurança alimentar de famílias rurais do Extremo Oeste de Santa Catarina. Revista Agropecuária Catarinense 31(3):44–49. https://doi.org/10.22491/RAC.2018.v31n3.5
Prasad R, Shivay YS, Kumar D (2017) Current status, challenges, and opportunities in rice production. In: Chauhan B, Jabran K, Mahajan G (eds) Rice production worldwide. Springer, Cham, pp 1–32
R Core Team (2016) R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org/. Accessed 20 Oct 2018
Raimondi JV, Marschalek R, Nodari RO (2014) Genetic base of paddy rice cultivars of southern Brazil. Crop Breed Appl Biotechnol 14:194–199. https://doi.org/10.1590/1984-70332014v14n3a29
Sahadevan PC, Namboodiri KMN (1963) Natural crossing in rice. Proc Indian Acad Sci Sect B 58:176. https://doi.org/10.1007/BF03051950
Sang T, Ge S (2007) Genetics and phylogenetics of rice domestication. Curr Opin Genet Dev 17(6):533–538. https://doi.org/10.1016/j.gde.2007.09.005
Sato S, Ishikawa S, Shimono M, Shinjyo C (1996) Genetic studies on an awnness gene An-4 on chromosome 8 in rice *Oryza sativa* L. Breed Sci 46(4):321–327. https://doi.org/10.1270/jsbbs1951.46.321
SBCS—Sociedade Brasileira de Ciência do Solo (2004) Manual de adubação e de calagem para os estados do Rio Grande do Sul e de Santa Catarina (ROLAS). Sociedade Brasileira de Ciência do Solo-Núcleo Regional Sul, Porto Alegre, Brazil
Singh V et al (2017) Rice production in the Americas. In: Chauhan B, Jabran K, Mahajan G (eds) Rice production worldwide. Springer, Cham, pp 137–168
Wickert E et al (2014) Exploring variability: new Brazilian varieties SCS119 Rubi and SCS120 Onix for the specialty rices market. Open J Genet 4(2):157–165. https://doi.org/10.4236/ojgen.2014.42016
Zeven AC (1998) Landraces: a review of definitions and classifications. Euphytica 104(2):127–139. https://doi.org/10.1023/A:1018683119237