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RESEARCH ARTICLE

SUSCEPTIBILITY OF 14 UPLAND RICE VARIETIES/LINES TO PLANT-PARASITIC NEMATODES

Bouma Thio[1]*, Kadougoudiou Abdourasmane Konaté[1] and Pascal Bazongo[2]

[1]Institute of Environment and Agricultural Research (INERA), Farako-Ba Station. BP 910. Bobo-Dioulasso, Burkina Faso; [2]Yembila Abdoulaye TOGUYENI University (University of Fada N'Gourma), High Institute for Sustainable Development, BP: 54. Fada N'Gourma, Burkina Faso

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Corresponding author: Bouma Thio

ABSTRACT

Rice is the third most important cereal crop in the world after wheat and maize, and the second most important in Africa after maize. In Burkina Faso, average annual rice production between 2010 and 2019 is estimated at 324,611 tonnes, representing less than half the country's needs. The susceptibility of fourteen (14) rice varieties and lines was conducted against plant-parasitic nematodes during the 2019-2020 wet cropping season at INERA, Farako-Bâ station (Bobo-Dioulasso). Five (5) main genera of parasitic nematodes of upland rice were identified and are represented by *Pratylenchus, Meloidogyne, Helicotylenchus, Scutellonema* and *Criconemella*. The root-knot nematode *Meloidogyne javanica* and the root-lesion nematode *Pratylenchus brachyurus* are considered the most important. Eight (8) lines from the *Oryza sativa* (Asian rice) x *O. barthii* (wild rice) cross and the FOFIFA (*O. sativa*) x NERICA (interspecific *O. sativa x O. glaberrima*) showed zero population densities of *Meloidogyne javanica* in soil (0 nematodes/dm3 soil) and low densities of *Pratylenchus brachyurus* in roots (less than 10 nematodes/g root).

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INTRODUCTION

Rice is the third cereal produced in the world after wheat and maize, and the second in Africa after maize. Indeed the demand for rice has increased from 10 Million tons in 1990 to 40 Million tonnaes in 2018 due to an ever-increasing demand because of high demography and dietary changes (Fiamohe *et al*., 2018; Muthayya *et al*., 2014). Rice production in Africa is 30% below demand, making the continent dependent on imports (Muthayya *et al*., 2014; Dawe, 2012). This dependence on imports, mainly from Southeast Asia and India, makes Africa vulnerable to external supply and price shocks (Niang *et al*., 2017). Rice production in Africa is currently characterized by high spatiotemporal variability in rice yields (Soullier *et al*., 2020), and the slow diffusion of high-yielding varieties annihilating the prdocutivity of rice in Africa (Nguezet *et al*., 2013; Minot, 2014). In Burkina Faso, average annual rice production between 2010 and 2019 is estimated at 324,611 tonnes, representing less than half the country's needs (Koutou *et al*., 2021). Given the importance of rice in Africa's diet, many African countries, where demand is growing rapidly, such as Burkina Faso, need to step up their efforts. This necessarily involves improving yields by combating bio-aggressors, notably parasitic rice nematodes. Research into rice varieties resistant to pests has mainly focused on diseases (fungi and viruses) and insect pests. Nicol *et al.* (2011) noted the existence of more than 4,100 species of plant-parasitic nematodes that can have a significant impact on global food security. Rice is attacked by around 35 genera of plant-parasitic nematodes, and 29 species are known to cause significant yield losses (Bridge *et al*., 2005).The first research in Africa aimed at improving nematode resistance through interspecific selection between *O. sativa* and *O. glaberrima* began at AfricaRice (formerly the Association for the Development of Rice in West Africa (ex-WARDA)) and was initially hampered by sterility problems among the F1 progeny (Ghesquière *et al*., 1997).Difficulties have been observed by several researchers in backcrossing interspecifics with *O. sativa* parents to obtain fertile offspring (Jones *et al*., 1997).The aim of this study was to investigate the susceptibility of rice lines derived from *O. sativa* (Asian rice) x *O. barthii* (wild rice) crosses, interspecific (NERICA) x *O. sativa* crosses and NERICA varieties (*O. sativa x O. glabrerrima*) to parasitic nematodes of upland rice.

MATERIALS AND METHODS

Experimental site: The study was conducted during the 2019-2020 wet cropping season at the Farako-Bâ research station (geographical coordinates 11.061N and -4.201W) of the (INERA). Farako-Bâ's climate is Sudano-Guinean. Annual rainfall varies from 1,000 to 1,400 mm, with a short rainy season (June to October) and a long dry season (November to May).

Experimental design: The experimental design is a completely randomized block comprising 14 fixed varieties/lines (Table 1) spotted 3 times. Rice varieties were selected by AfricaRice and included *O. sativa* varieties, interspecific varieties resulting from crosses of *O. sativa* (Asian rice) x *O. glaberrima* (African rice) and interspecific *O. sativa x O. barthii* (wild rice). Varieties resulting from backcrossing were also evaluated (FOFIFA 161 x NERICA 3 or 4). Four widely-popular control varieties were selected, including 2 NERICA interspecifics (FKR 45N and NERICA 4) and 2 *O. sativa* varieties (FKR 61 and FKR 59).

Nematode extraction: Nematodes are extracted from the soil using the Seinhorst (1962) elutriator method. A 250-cubic-centimeter soil sample is washed through a millimeter-mesh sieve by the action of a stream of water, to remove coarse particles. During active filtration, the current retains the nematodes, while the heavy particles sink to the bottom of the column. In the passive filtration phase, the nematodes are separated from the impurities according to their mobility, by pouring the contents of the active filtration onto Kleenex paper containing a fine-mesh sieve placed in a plate for 48 hours. Nematodes present in the roots are extracted using the Seinhorst (1950) sprinkler method. The roots are kept continuously for 14 days in a water mist. The moisture in the roots causes them to decompose, releasing the nematodes. After 14 days, the nematodes retained in the container are recovered by active filtration for 48 hours. Nematode populations extracted from soil samples are expressed as number of nematodes per cubic decimeter (N/dm^3) and those extracted from roots as number of nematodes per gram of fresh root (N/g). Morphological identification of nematodes is based on the identification key of Mai and Lyon (1975).

Data analysis: Analysis of variance (ANOVA) was performed using XLSTAT 2016 software, and means were separated using the Newman-Keuls test at a significance level of 5%. Data from nematological observations were transformed into Log10(X + 1) where X is the observed value given when the coefficient of variation is high.

RESULTS

Nematode populations associated with strict rainfed rice: Nematological observations carried out during sowing of strict rainfed rice showed the presence of seven (07) species of plant-parasitic nematodes represented by *Pratylenchus brachyurus, Meloidogyne javanica, Helicotylenchus dihystera, Scutellonema cavenessi, Tylenchorhynchus* sp., *Criconemella onoensis, Xiphinema* sp. (Table 2). The nematodes *Helicotylenchus dihystera* and *Scutellonema cavenessi* were observed in all samples at rice sowing (100%) at densities of 847 and 217 nematodes/dm^3 of soil respectively. Root lesion nematode *Pratylenchus brachyurus* and the root-knot nematode *Meloidogyne javanica*, considered the most dangerous for upland rice, were observed at frequencies of 83 and 66%, with densities of 257 and 93 nematodes/dm^3 of soil respectively. The other groups of nematodes, represented by *Tylenchorhynchus* sp., *Xiphinema* sp. and *Criconemella onoensis*, were observed at frequencies of between 16% and 66%, with population densities ranging from 3 to 57 nematodes/dm^3 of soil.

Susceptibility of strict rainfed rice varieties to plant-parasitic nematodes: To study the susceptibility of upland rice varieties and lines, nematological observations were made at harvest, and concerned the main plant-parasitic nematodes known to cause crop damage, represented by *Pratylenchus brachyurus, Meloidogyne javanica, Helicotylenchus dihystera, Scutellonema cavenessi* and *Criconemella* (Table 3). Root the lesion nematode *Pratylenchus brachyurus* was observed in rice roots.The root-knot nematode *Meloidogyne javanica* was only observed in soil samples from a few varieties/lines, namely V5 (PCT-4\SA\1\1SA\2\1>746-1-5-2-2-M), V11 (FKR 45N (Control)), V12 (FKR 61 (Control)) and V14 (FKR 59 (Control)), with population densities ranging from 7 to 100 nematodes/dm^3 of soil ($P < 0.05$). The majority of varieties from the *Oryza sativa*(Asian rice) x *O. barthii* (wild rice) cross (V1, V2, V3, V4, V6, V10), the *O. sativa x O. glaberrima* cross (V14) and FOFIFA161 (*O. sativa*) x NERICA 3/4 (V7, V8, V9) showed zero population densities (0 nematodes/dm^3 soil).The root lesion nematode *Pratylenchus brachyurus* was observed in soil samples and roots. Low population densities of the soil-extracted nematode were observed in varieties V3 (ART 35-200-2-2-B-1) and V4 (ART 27-58-8-1-2-3) from the *Oryza sativa x O. barthii* cross, with 60 and 73 nematodes/dm^3 soil respectively ($P < 0.05$).

For nematodes extracted from roots, varieties V1 (ART 35-272-1-2-B-1), V2 (ART 3-7L9P8-3-B-B-2-1), V3 (ART 35-200-2-2-B-1), V4 (ART 27-58-8-1-2-3), V5 (PCT-4\SA\1\1SA\2\1>746-1-5-2-2-M), V6 (ART 35-49-1-4N-1) and V9 (PCT-4\SA\5\1>1754-5-1-3-2-2-M) showed low population densities ($P < 0.05$).These varieties/lines are derived from crosses *Oryza sativa x O. barthii* and FOFIFA161 (*O. sativa*) x NERICA 3/4.The spiral *nematode Helicotylenchus dihystera* was observed at low densities on varieties V3 (ART 35-200-2-2-B-1), V4 (ART 27-58-8-1-2-3) and V13 (FKR 59 (Control)) from crosses *Oryza sativa x O. barthii* and an *O. sativa* variety from the varieties ($P < 0.05$). For the nematode *Criconemella onoensis*, the lowest densities were observed under the varieties/lines V3 (ART 35-200-2-2-B-1) and V14 (NERICA4 (Control)) derived from the crosses *Oryza sativa x O. barthii* and *Oryza sativa x O. glaberrima* respectively ($P < 0.05$). Considering total populations of soil parasitic nematodes, the varieties/lines least attacked are represented by V3 (ART 35-200-2-2-B-1), V4 (ART 27-58-8-1-2-3) and V5 (PCT-4\SA\1\1SA\2\1>746-1-5-2-2-M) from crosses *Oryza sativa* x *O. barthii* and FOFIFA161 (*O. sativa*) x NERICA 3/4 ($P < 0.05$).

Hierarchical ascending classification of rice varieties according to plant-parasitic nematode population densities: An analysis of the groupings of rice variety and line classes according to the population levels of the main plant-parasitic nematodes is given in Figure 1.

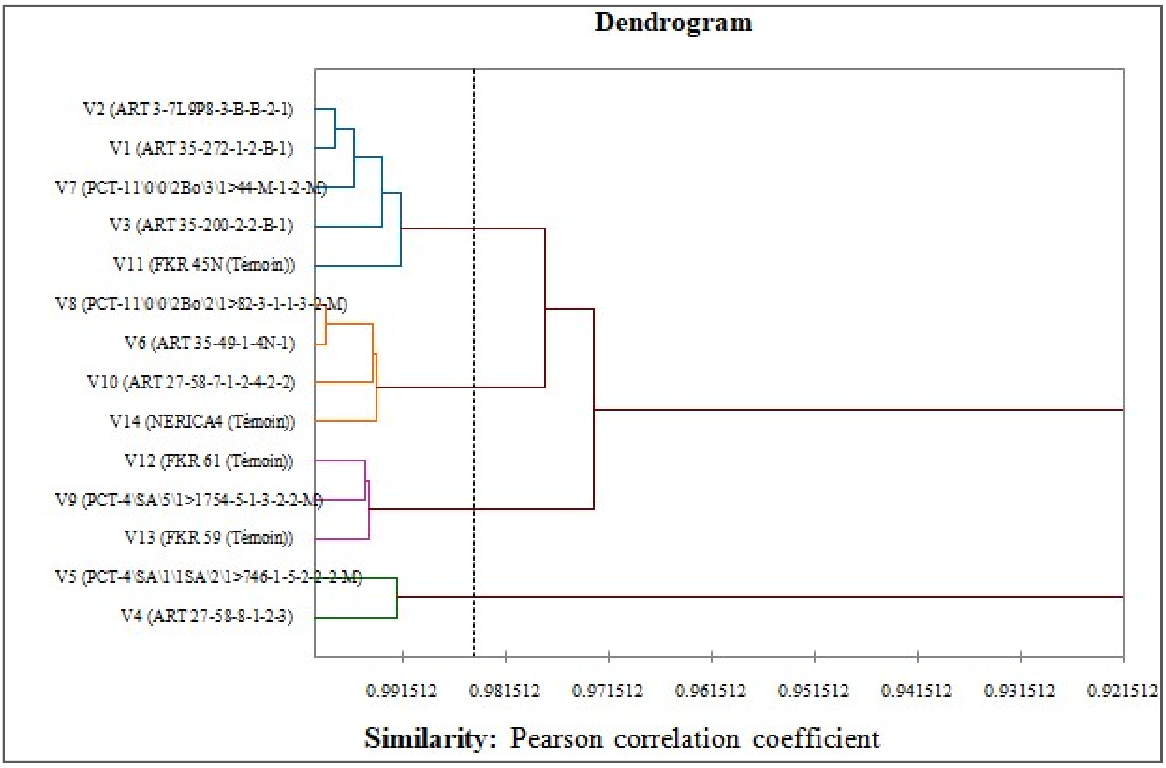

Figure 1. Dendrogram of analysis of susceptibility of rice varieties/lines to plant parasitic nematodes

Table 1. List of rice varieties/lines

N°	Varieties/lines	Type of crossing	Breeder
V1	ART 35-272-1-2-B-1	*Oryza sativa x O. barthii*	Africa Rice
V2	ART 3-7L9P8-3-B-B-2-1	*Oryza sativa x O. barthii*	Africa Rice
V3	ART 35-200-2-2-B-1	*Oryza sativa x O. barthii*	Africa Rice
V4	ART 27-58-8-1-2-3	*Oryza sativa x O. barthii*	Africa Rice
V5	PCT-4\SA\1\1SA\2\1>746-1-5-2-2-2-M	FOFIFA161 x NERICA ¾	Africa Rice
V6	ART 35-49-1-4N-1	*Oryza sativa x O. barthii*	Africa Rice
V7	PCT-11\0\0\2Bo\3\1>44-M-1-2-M	FOFIFA161 x NERICA ¾	Africa Rice
V8	PCT-11\0\0\2Bo\2\1>82-3-1-1-3-2-M	FOFIFA161 x NERICA ¾	Africa Rice
V9	PCT-4\SA\5\1>1754-5-1-3-2-2-M	FOFIFA161 x NERICA ¾	Africa Rice
V10	ART 27-58-7-1-2-4-2-2	*Oryza sativa x O. barthii*	Africa Rice
V11	FKR 45N (Control)	*Oryza sativa x O. glaberrima*	Africa Rice
V12	FKR 61 (Control)	*Oryza sativa*	Africa Rice
V13	FKR 59 (Control)	*Oryza sativa*	Africa Rice
V14	NERICA 4 (Control)	*Oryza sativa x O. glaberrima*	Africa Rice

Legend: FOFIFA 161/IRAT 114 x FOFIFA 133 (*Oryza sativa ss japonica*)

Table 2. Population densities of the main parasitic nematodes of upland rainfed rice before sowing

Genera of nematodes	Frequency (%)	Number of nematodes/dm^{3}of soil			
		Min.	Max.	Average	Standard deviation
Helicotylenchus multicinctus	100	440	1340	847	304
Scutellonema cavenessi	100	100	340	217	94
Pratylenchus brachyurus	83	0	620	257	65
Meloidogyne javanica	66	0	340	93	139
Tylenchorhynchus sp.	66	0	200	57	74
Xiphinema sp.	33	0	20	7	10
Criconemella onoensis	16	0	20	3	8

Legend: Min: minimum; Max: maximum

The groupings of varieties/lines are mainly associated with the population densities of the parasitic nematodes most damaging to rice cultivation in the rainfed ecology. Hierarchical ascending classification (HAC) using the similarity method (Pearson coefficient) reveals four (4) groups or clusters. Cluster 1 includes 5 varieties/lines [V1 (ART 35-272-1-2-B-1), V2 (ART 3-7L9P8-3-B-B-2-1), V3 (ART 35-200-2-2-B-1), V7 (PCT-11\0\0\2Bo\3\1>44-M-1-2-M) and V11 (FKR 45N (Control))] derived from the cross *O. sativa x O. barthii* for V1, V2, V3 and FOFIFA (*O. sativa*) x NERICA (V7) and V11 (*O. sativa x O. glaberrima*). These varieties are characterized by zero population densities of *Meloidogyne javanica* (0 nematodes/dm^3 of soil). Varieties V1, V2 and V3 showed population densities of the lesion nematode *Pratylenchus brachyurus* of between 1 and 10 nematodes/g of roots. These cross-bred varieties are interesting in that they are not attacked by *M. javanica* and also have low infestations of Pratylenchus

Table 3. Population densities of the main parasitic nematodes of strict rainfed rice according to varieties/lines

N°	Varieties/lines	Type of crossing	Melo/dm^3	Praty/dm^3	Helico/dm^3	Crico/dm^3	Total/dm^{3}of soil	Praty/g of root
V01	ART 35-272-1-2-B-1	*Oryza sativa x O. barthii*	0 a	560 ab	113 b	173 b	846 b	1,2 a
V02	ART 3-7L9P8-3-B-B-2-1	*Oryza sativa x O. barthii*	0 a	213 a	47 ab	87 ab	347 ab	6,5 a
V03	ART 35-200-2-2-B-1	*Oryza sativa x O. barthii*	0 a	60 a	20 a	27 a	107 a	9,7 a
V04	ART 27-58-8-1-2-3	*Oryza sativa x O. barthii*	0 a	73 a	27 a	73 ab	173 ab	3,4 a
V05	PCT-4\SA\1\1SA\2\1>746-1-5-2-2-2-M	FOFIFA161 x NERICA 3 or 4	13 ab	127 a	40 ab	93 ab	273 ab	3,8 a
V06	ART 35-49-1-4N-1	*Oryza sativa x O. barthii*	0 a	567 ab	60 ab	93 ab	727 b	6,6 a
V07	PCT-11\0\0\2Bo\3\1>44-M-1-2-M	FOFIFA161 x NERICA 3 or 4	0 a	360 ab	100 ab	107 ab	567 b	36,8 b
V08	PCT-11\0\0\2Bo\2\1>82-3-1-1-3-2-M	FOFIFA161 x NERICA 3 or 4	0 a	993 b	67 ab	147 ab	1207 c	33,8 b
V09	PCT-4\SA\5\1>1754-5-1-3-2-2-M	FOFIFA161 x NERICA 3 or 4	0 a	367 ab	53 ab	40 ab	567 b	6,7 a
V10	ART 27-58-7-1-2-4-2-2	*Oryza sativa x O. barthii*	0 a	280 ab	60 ab	47 ab	387 b	16,3 ab
V11	FKR 45N (Control)	*Oryza sativa x O. glaberrima*	7 a	260 a	33 ab	87 ab	380 b	35,7 b
V12	FKR 61 (Control)	*Oryza sativa*	100 b	400 ab	87 ab	80 ab	667 b	19,8 ab
V13	FKR 59 (Control)	*Oryza sativa*	85 b	313 ab	27 a	67 ab	492 b	18,8 ab
V14	NERICA4 (Control)	*Oryza sativa x O. glaberrima*	0 a	253 a	40 ab	13 a	306 b	16,7 ab
	Probability > F		0,015	0,025	0,035	0,031	0,045	0,047
	Signification		*	*	*	*	*	*

Legend: *Prat.:*Number of*Pratylenchus; Melo.:*Number of *Meloidogyne; Heli.:*Number of *Helicotylenchus; Scut.:*Number of *Scutellonema; Cric. :* Number of *Criconemella.* Means followed by the same letter are not significantly different according to the Newman-Keuls test at the threshold of 5%.

brachyurus, considered to be the main nematodes causing major losses on upland rice.

Cluster 2 includes 2 varieties/lines [V4 (ART 27-58-8-1-2-3) and V5 (PCT-4\SA\1\1SA\2\1>746-1-5-2-2-M)] including V4 from the *O. sativa x O. barthii* cross and V5 (FOFIFA (*O. sativa*) x NERICA). These varieties are characterized by low root population densities of *Pratylenchus brachyurus* (3 nematodes/g of root) and low total soil population densities (172-280 nematodes/dm^3 of soil).

Cluster 3 includes 4 varieties/lines [V6 (ART 35-49-1-4N-1), V8 (PCT-11\0\0\2Bo\2\1>82-3-1-1-3-2-M), V10 (ART 27-58-7-1-2-4-2-2) and V14 (NERICA4 (Control))] from the *O. sativa x O. barthii* cross (V6 and V10), the FOFIFA (O. sativa) x NERICA cross (FOFIFA (*O. sativa*) x NERICA and the *O. sativa x O. glaberrima* cross (V14). These varieties are characterized by zero population densities of *M. javanica* (0 nematodes/dm^3 of soil). These varieties are also characterized by average population densities of *Pratylenchus brachyurus* extracted from roots (7 to 34 nematodes/g of roots).

Cluster 4 comprises 3 varieties [V9 (PCT-4\SA\5\1>1754-5-1-3-2-2-M), V12 (FKR 61 (Control)) and V13 (FKR 59 (Control))] derived from the FOFIFA (*O. sativa*) x NERICA (V9) and *O. sativa x O. sativa* (V12 and V13) crosses. These varieties are characterized by high densities of *M. javanica* (73 to 100 nematodes/dm^3 of soil) and root population densities of *P. brachyurus* ranging from 7 to 20 nematodes/g of roots. These varieties are of no interest in a varietal crossing program, as they are attacked by both parasitic nematodes, causing high yield losses in rainfed rice.

DISCUSSION

Parasitic nematode communities associated with rainfed rice: Our research results corroborate those of several research works on parasitic nematode communities of rice produced under rainfed conditions. Research by Thio *et al*. (2017) on the inventory of parasitic nematodes associated with rice in the rainfed ecology of Burkina Faso identified around ten genera/species, the most important of which are represented by the genera *Scutellonema, Tylenchorhynchus, Helicotylenchus, Pratlenchus* and *Criconemella*. Two major species of root-knot nematodes are known to cause serious damage to rice: *Meloidogyne javanica*, which is present in upland areas, and *Meloidogyne graminicola*, which mainly infests flooded rice. Indeed, the root-knot nematode *M. graminicola* is a major constraint on rice in Asia (De Waele & Elsen, 2007; Mantelin *et al*., 2017). On the other hand, *M. javanica* is a major parasitic nematode of rice throughout Africa (Coyne *et al*., 1999; 2018; Udo *et al*., 2011). As for the root lesion nematode *Pratylenchus* spp., it is mainly infested with upland crops including upland rice (strict rainfed) and is considered the most frequent parasitic nematode in this ecology (Bridge *et al*., 2005; Pascual *et al*., 2014). *Helicotylenchus dihystera* is reported to be important in strict rainfed rice cultivation and on the upper parts of lowlands in Côte d'Ivoire (Coyne *et al*., 1998). *Tylenchorhynchus* spp. is common to rice produced in all rice-growing ecologies, but its pathogenicity is not often reported on rice, as the nematode is highly polyphagous (Bridge *et al*., 2005).

Susceptibility of rice varieties/lines to plant-parasitic nematodes: Research into rice productivity has focused primarily on the selection of varieties resistant to pests, including plant-parasitic nematodes. In the case of rice parasitic nematodes, research has focused on species/genera likely to cause significant yield losses. In the case of upland rice, the nematodes concerned are mainly root-knot nematodes of the *Meloidogyne* genus, cyst nematodes of the *Heterodera* genus and root-lesion nematodes *Pratylenchus* spp. Our study reveals that *Meloidogyne javanica* and *Pratylenchus brachyurus* are the nematode species that emerge from population density and hierarchical ascending classification (HAC) analyses. In particular, the study revealed that rice varieties derived from crosses of *Oryza sativa x O. barthii* (Asian rice x wild rice) and varieties derived from crosses of *O. sativa x O. glaberrima*(Asian rice x African rice) showed zero population densities of *Meloidogyne javanica* in the soil (0 nematodes/dm^3 of soil) and low densities of *Pratylenchus brachyurus.* Several studies have shown that some NERICA (New Rice for Africa) rice varieties, mainly hybrids derived from *Oyza sativa x O. glaberrima*crosses, were resistant to the cyst nematode *Heterodera sacchari* and the root-knot nematode *Meloidogyne* sp. with resistance genes from the African parent *O. glaberrima* (Cabasan *et. al*., 2012; Lorieux *et al*., 2003; Plowright *et al*., 1999). Accessions of *O. longistaminata* (wild rice) and *O. glaberrima* (African rice) have shown resistance to *Meloidogyne* spp. (Cabasan*et al*. 2012; Petitot*et al*. 2017; Soriano *et al*. 1999). Recentwork by Lahari*et al.*(2020) has shown resistance of the African rice variety TOG5674 to the nematodes *M. javanicaand Pratylenchus zeae.*

CONCLUSION

The study of the susceptibility of fourteen (14) varieties and lines of rainfed rice resulting from crosses of *O. sativa* (Asian rice) x *O. barthii* (wild rice), NERICA varieties (*O. sativa x O. glaberrima)* and interspecific backcrosses (NERICA) x *O. sativa* enabled us to identify five (5) main genera of parasitic nematodes associated with rainfed rice at the INERA Farako-Bâ station. These nematodes belong to the genera *Pratylenchus, Meloidogyne, Helicotylenchus, Scutellonema* and *Criconemella*. The root-knot nematode *Meloidogyne javanica* and the root-lesion nematode *Pratylenchus brachyurus* are considered the most important. Eight (8) lines showed zero population densities of *Meloidogyne javanica* in soil (0 nematodes/dm^3 soil) and low densities of Pratylenchus brachyurus in roots (less than 10 nematodes/g root).

These are lines derived from the *Oryza sativa* (Asian rice) x. *Barthii* (wild rice) [V1 (ART 35-272-1-2-B-1), V2 (ART 3-7L9P8-3-B-B-2-1), V3 (ART 35-200-2-2-B-1), V4 (ART 27-58-8-1-2-3),V5 (ART 35-49-1-4N-1), V6 (ART 35-49-1-4N-1)] and line V9 PCT-4\SA\5\1>1754-5-1-3-2-2-M from the FOFIFA (*O. sativa*) x NERICA (interspecific *O. sativa x O. glaberrima*). Wild rice species (*Oryza barthii*) and African rice varieties (*O. glaberrima*) possess genes for resistance to the nematodes *Meloidogyne javanica* and *Pratylenchus brachyurus*, which can be transferred to progeny during crossbreeding.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

CONFLICTS OF INTEREST: The authors have declared that there are no competing interests.

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