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Increase rice production through improved varieties cultivation in Côte d'Ivoire

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Abstract

Rice (*Oryza sativa* and *O. glaberrima*) is among important cereal widely consumed in the world, with wheat and maize. Due to its high demand, increase rice production, mostly in sub-Saharan Africa countries such Côte d'Ivoire remains a key issue to reduce rice imports. Consequently, rice breeding programs improve and release new rice cultivars to the farmers. This study was aimed to evaluate the agroecological zone effect on the new improved (IRV) and adopted (ARV) rice varieties' yields. The experiment was conducted in a split-plot design. Data collected on five parameters, including yield and yield components, were collected and analyzed. Means comparison was done with Dunnett's test using WITA9 means as control. The results showed significant difference between moisture content, grain and straw yields and harvest index of improved rice and the ones of adopted rice's means. The means of grain yield of IRV of 6.82 t ha^{-1} was higher than that of ARV of 2.87 t ha^{-1}. The grain yield of the control variety WITA9 was 6.56 t ha^{-1}. The Dunnett's test showed that only the grain yield of AR043H was significantly higher than that of the control with 8.15 t ha^{-1}. The varieties GT11 (5.03 t ha^{-1}), Soungrouba (4.62 t ha^{-1}), Djoukemé (2.80 t ha^{-1}), Marigbè (1.54 t ha^{-1}), Palawan (1.53 t ha^{-1}), Danané (1.38 t ha^{-1}), Demamba (0.97 t ha^{-1}) and Kouiklonlé (0.95 t ha^{-1}) had significantly lower yields than the yield of WITA9. The result from this experiment showed the role that improved varieties could play in increase rice production in Côte d'Ivoire.

Keywords: Rice; Cultivars; Savannah zone; Hybrids; Agronomic traits; Ivory Coast

1. Introduction

Rice is one of the most produced grains in the world, surpassed only by corn and wheat with about over 40,000 varieties [1]. Sub-Saharan Africa, mainly west Africa, has a long history of rice cultivation [2]. However, the volume of annual rice imports by sub-Saharan countries increased from 14.589 thousand metric tons in 2017/2018 to 16.460 thousand metric tons in 2021/2022 [1]. Côte d'Ivoire, a western country of Africa, is the sixth-largest rice producer in Sub-Saharan Africa. However, the country faces a 30 % shortfall in its consumption of milled rice [3, 4] and rice imports cross the FCFA 500 billion level in 2022 [5]. The national productions gaps observed in rice production could be due to different factors such as physical factors, biophysical factors, socio-economic factors and Institutional factors [6].

Côte d'Ivoire has a favourable climate, sufficient rainfall, important hydrography, a long rice cultivation tradition among rural populations and important land area suitable for growing rice. To reduce its rice imports and fill the gap of the population needs, Côte d'Ivoire elaborates two main strategies: reinforce seeds quality and mechanize rice production system. The country decides to increase the current mechanization rate of about 5% to 30% by 2025 [7]. In fact, modern rice cultivation practices include mechanization. Mechanization has proved efficiency in boosting rice production,

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namely in Asia [8, 9], while in sub-Saharan Africa the investment in agricultural mechanization remain low and insufficient to raise rice production [10]. Moreover, rice production system mechanization is the way to improve irrigation system and also reduce climate change impact.

The reinforcement of seeds' quality remains the main strategy to increase rice production. By far, about 84 % of the rice-production growth has been attributed to modern farming technologies that have produced rice varieties that can be planted up to three times per year, including hybrids with higher yield potential [11, 12].

Early in the 70s, west Africa established the West Africa Rice Development Association (WARDA) which became Africa Rice Center (AfricaRice) in 2009, with its Headquarter in Bouaké, Côte d'Ivoire. Breeding programmes have released new varieties with important agronomic traits. By crossing African rice accession CG14, *Oryza glaberrima* Steud. (most cultivated in west Africa) by the high-yielding Asian rice, *O. sativa* L., WARDA produced the New Rice for Africa (NERICA) cultivars that revolutionized rice cultivation in west Africa [13, 14].

In Côte d'Ivoire, small-scale farmers continue to cultivate traditional rice varieties, which give low yields and may be vulnerable to environmental stresses [15]. However, improved rice varieties have been released and some have been adopted by farmers. Furthermore, the quest for sustainable rice production encompasses the development and adoption of climate-smart rice varieties because climate change is projected to significantly influence rice production [16]. As it is, breeding activities should release rice varieties which are more resilient to various climate stresses, such as drought, heat, flooding and biotic stresses while maintaining high yields and Improved nutritional value [17]. Consequently, this study aimed to evaluate the effect of agroecological zone of central Côte d'Ivoire on improve rice varieties (IRV) and adopted local rice varieties (ARV) yielding.

2. Material and methods

2.1. Plant material

Domesticated rice was the plant used in this experiment. Plant materials were composed of adopted varieties and newly improved varieties of rice. In this manuscript adopted local rice varieties (ARV) are identified as varieties well cultivated by farmers, including traditional and released improved rice varieties. The improved rice varieties (IRV) are newly improved varieties not yet vulgarised. Ten ARV composed of Palawan, Djoukemé, GT11, Danané, Demamba, Kouiklonlé, Soungrouba, Marigbè, Koitè and WITA9. WITA9 was used as control variety. WITA9 (WITA stands for **W**ARDA at I**ITA**) is the predominant variety in the lowlands of Côte d'Ivoire (known locally as "Nimba"), released in 1998 [18]. Its paddy yield advantage is estimated to 0.7 t ha^{-1}. WITA9 is Early maturity and resistant to rice yellow mottle virus [19]. The IRV were collected from AfricaRice, Saint-Louis Research Center, Senegal. They were composed of AR624H, AR593H, AR034H, AR051H, AR630H, AR043H, AR601H, AR638H, AR629H and AR597H. The potential yield of the IRV was 9 – 10 t ha^{-1}. All the plant materials used were lowland rice varieties.

2.2. Experimental site and soil properties

The experiment was conducted at M'bé station, in Bouaké region (8°06″ N, 6° W), middle Côte d'Ivoire. The experimental site was a lowland under irrigation and semi-developed. The agroecological zone was characterized by a bimodal rainfall pattern under a subtropical climate, with an average temperature rainfall of 28 °C and 1200 mm, respectively. The land was under a five-year fallow dominated by *Leersia hexandra* (Poaceae) and *Frimbristulis* spp (Poaceae).

The soil originated from granito-gneiss and classified as Fluvisol having pH_{H2O} = 5.5, OC = 3.12 g kg^{-1}, total nitrogen = 0.31 g kg^{-1}, assimilable phosphorus (Olsen method) = 150 mg kg^{-1}, potassium = 0.08 cmol kg^{-1}, calcium = 3.05 cmol kg^{-1}, magnesium = 2.26 cmol kg^{-1}, CEC = 2.02 cmol kg^{-1}. The C:N ratio and [(K:CEC) × 100] ratio were 10.06 and 3.9 %, respectively.

2.3. Experimental setup and design

An area of 1815 m^2 was cleaned and was ploughed. A motorized cultivator was used for puddling and drainage operations. The whole plot was subdivided into subplots separated by 3 m apart. Within a subplot, micro-plots of 15 m^2 (3 m × 5 m) were set and separated by 1 m space. The experiment was in split-plot design using the variety group (hybrid or local) as main factor and the variety as subfactor.

NPK fertilizer (15-15-15) was applied as basal dressing at a rate of 200 g per 15 m^2. Thereafter, the plants were transplanted with a spacing of 20 cm × 20 cm, after 21 days in the nursery, with one plant per hill. Irrigation was provided through the drainage canal with water intake based on water flow. Following the normal fertilizer application rate, urea was applied at rates of 14 g per 15 m^2 at tillering and 19 g per15 m^2 at flowering.

A total herbicide treatment (active ingredient: glyphosate isopropylamine salt) was applied after the first ploughing at a dose of 360 g L^{-1} to eradicate all plant growth on the site. Two weeks after transplanting, a selective herbicide (active ingredient: propanil (360 g L^{-1}) + trichopyr) was used to treat rice plants at a dose of 72 g L^{-1}, to control weeds. Four weeks after transplanting, all subplots were irrigated to reach and maintain a maximum water level of 5 cm. When insects' attacks occurred, insecticide DECIS (Lambda cyhalothrin) was applied at a dose of 30 g L^{-1}. Two manual weedings were made during the experiment.

2.4. Data collection

Rice was harvest from 8 m^2 leaving the two border lines to avoid border effect. After threshing and drying, the straw was weighed, while the rice grains were winnowed before weighed. Grain moisture content was determined after oven drying at 70 °C for 24 hours. The grains yield was calculated based on the standard moisture of 14 % [20]. Data were collected on moisture content, straw and grain yields, total dry matter and harvest index.

2.5. Statistical analysis

Data collected were submitted to an analysis of variance (ANOVA) in general linear model (GLM). First of all, Tukey HSD Test was used to separate the means of local and hybrids yield and associated parameters. Thereafter, Dunnett test was conducted using WITA9 data as control data in Minitab 17.1.0. The means were compared at P = 0.05. Correlation was used to test the relationship between the recorded rice biomasses and soil pH.

The 20 studied rice genotypes were grouped into three different clusters based on the mean performance of five agronomical traits: grain moisture content, straw and grain yields and harvest index. The Ward's linkage method of classification based on the Euclidean distance was used [21]. Minitab 17.1.0 and R version 4.3.1 were used as statistical analysis packages

3. Results

3.1. Moisture yields and harvest index of rice variety type

The analysis of the results showed significant differences between local and hybrid varieties relatively to their grain humidity content, dry grain and straw yields, and harvest index (Table 1). Hybrids' grain yield was about 2.37 times local grain yield. In addition, the hybrids' straw yield was higher than the one of the local varieties.

Table 1 Moisture content, dry straw and grain yield, and harvest index of local and hybrid rice varieties

Variety types	Grain moisture (%)	Dry grain yield (kg ha^{-1})	Dry straw yield (kg ha^{-1})	Harvest Index
Adopted rice varieties	13.28 b	2.87 b	5.32 b	0.32 b
Improved rice varieties	15.06 a	6.82 a	11.02 a	0.39 a

(Means with different letter are significantly different, at P = 0.5)

3.2. Grain moisture content

Significant difference was observed between the control Wita9 and some of the varieties relatively to grain moisture content. The local variety Kouiklonlé has the least moisture content of 10.90 % while the local variety Soungrouba had the highest moisture 16.48 %. The control variety WITA9' moisture content was 11.68 %. Dunnett simultaneous tests showed seven varieties which had higher moisture content than the control WITA9 (Figure 1).

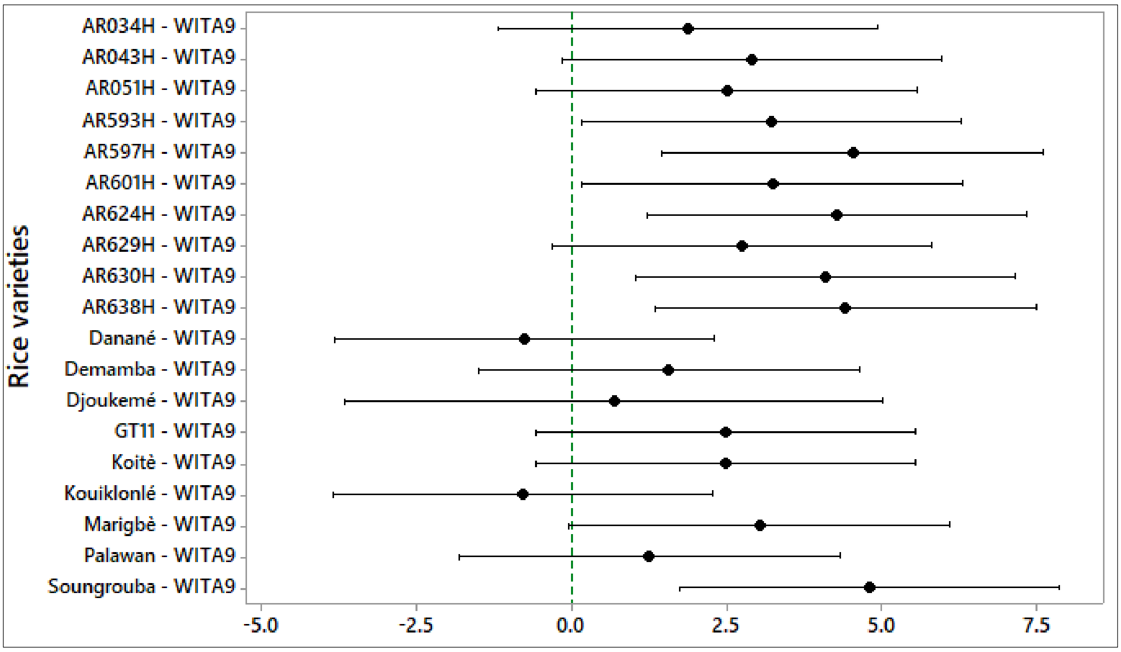

Figure 1 Dunnett simultaneous tests for level mean minus control WITA9 mean of moisture content (If an interval does not contain zero, the corresponding mean is significantly different from the control mean)

3.3. Straw yields

The highest straw yield was produced by the hybrid AR638H with 13.76 t ha^{-1} (Figure 2). Significant difference was observed between the control WITA9 and GT11, Palawan, Koitè, Demamba, Danané and Kouiklonlé which produced 1.840 t ha^{-1} (Figure 3). The dry straw yield of WITA9 was 10.51 t ha^{-1}.

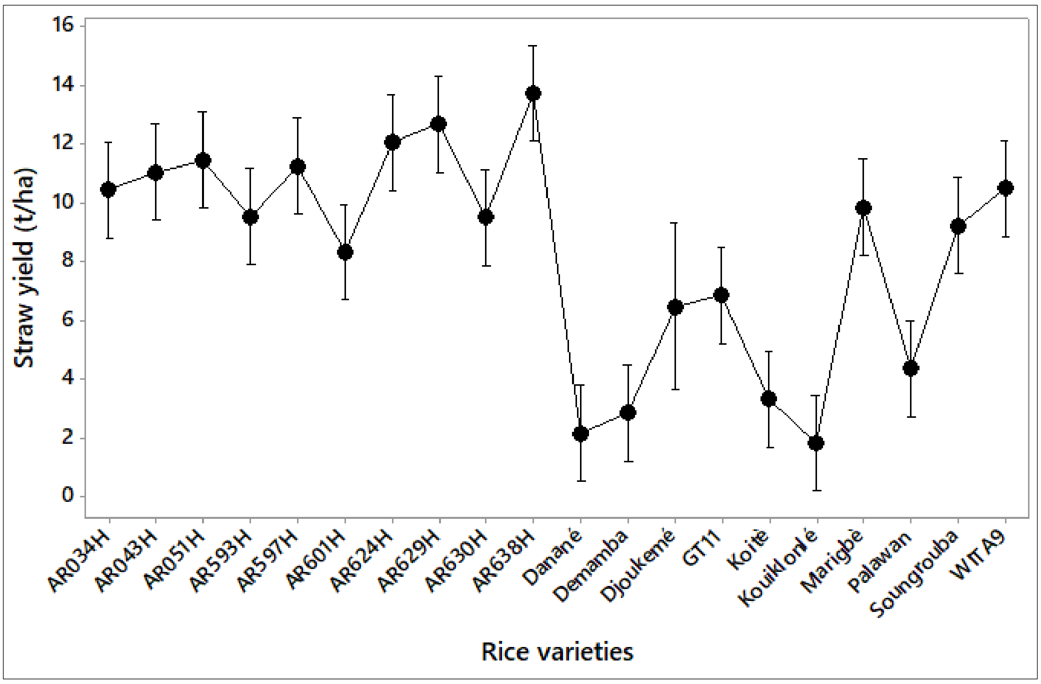

Figure 2 Straw yield of local and hybrid rice

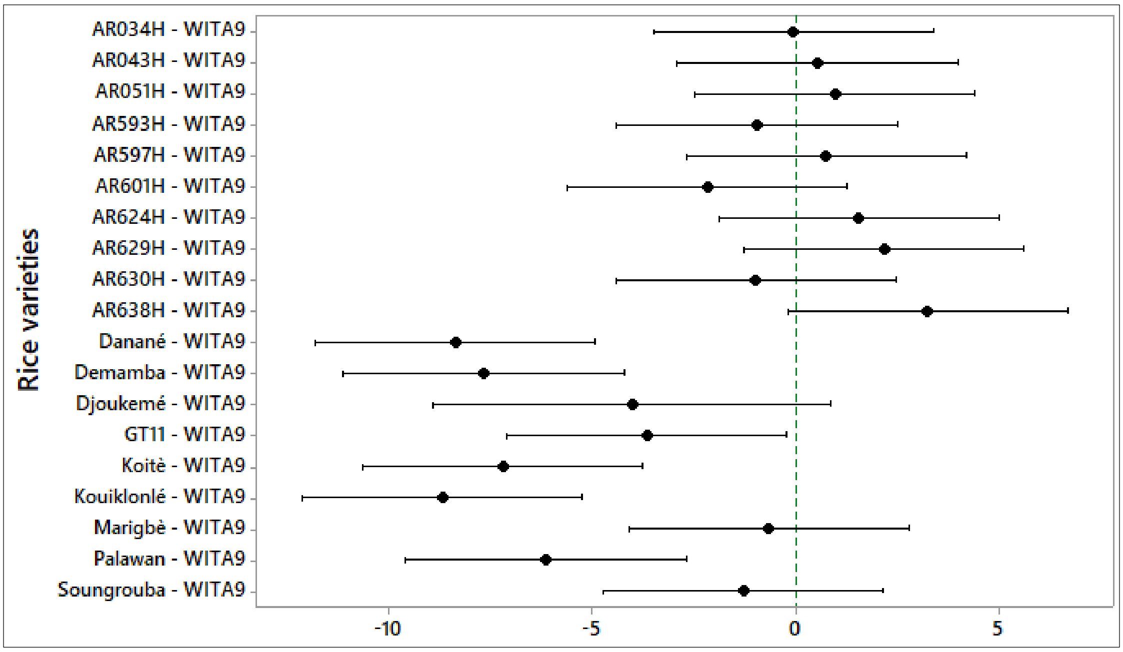

Figure 3 Dunnett simultaneous tests for level mean minus control WITA9 mean of straw yields (If an interval does not contain zero, the corresponding mean is significantly different from the control mean)

3.4. Grain yield

The grain yield varied from 0.95 to 8.15 t ha^{-1} (Figure 4). The control variety WITA9 produced 6.55 t ha^{-1}. The analysis showed significant differences among rice yields. Only variety AR043H had a significant higher grain yield of 8.15 t ha^{-1} than the one of the control variety WITA9 of 6.56 t ha^{-1} (Figure 5).

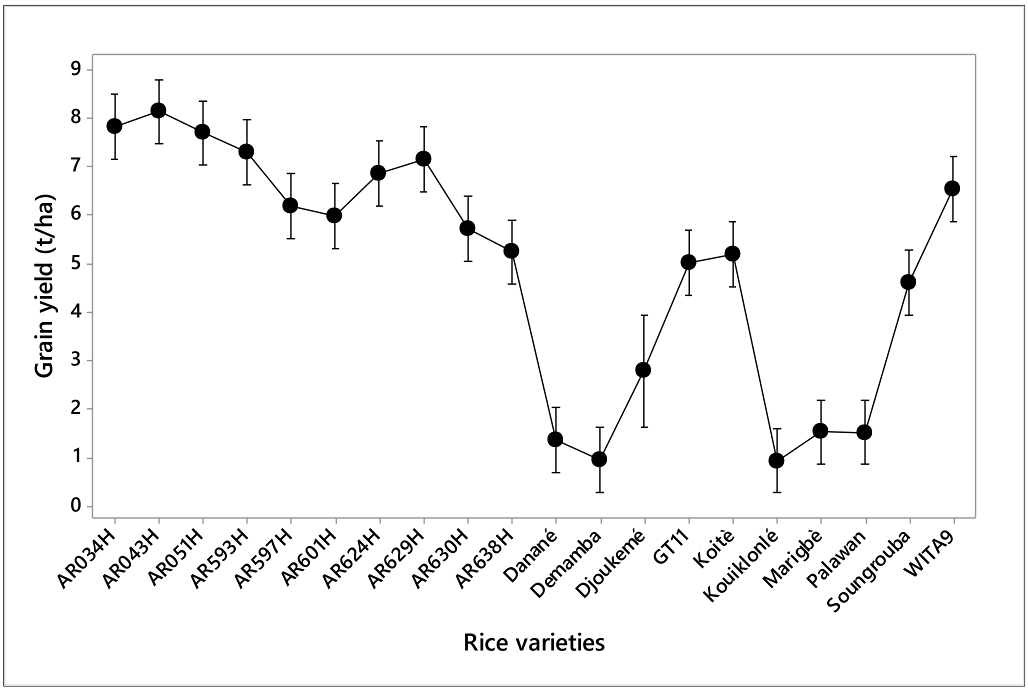

Figure 4 Grain yield of improved and adopted rice varieties

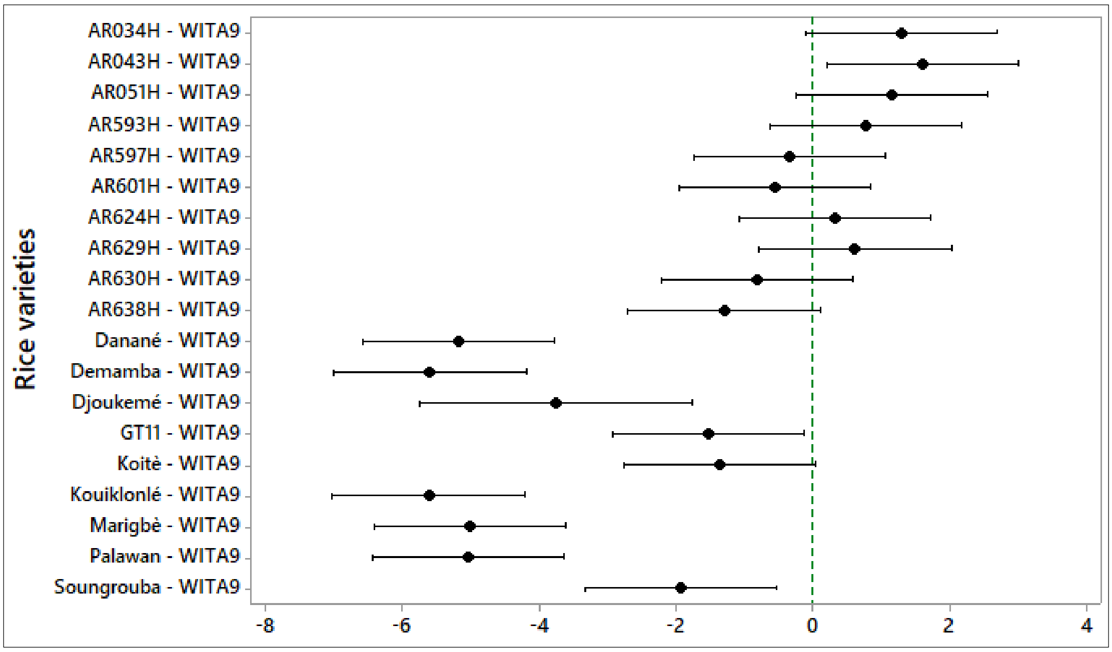

Figure 5 Dunnett simultaneous tests for level mean minus control WITA9 mean of rice grain yields (If an interval does not contain zero, the corresponding mean is significantly different from the control mean)

3.5. Harvest index

The harvest index varied from 0.13 to 0.62. The highest harvest index was obtained by the local variety Koitè. Significant differences were found between the control variety WITA9 harvest index and the ones of Koitè, AR638H, Demamba, Palawan and Marigbè (Table 2).

Table 2 Harvest index means of improved and adopted rice varieties

Genotype	**WITA9 (Control)**	**Koitè**	**AR034H**	**AR601H**	**AR593H**
Harvest index	0.39 A	0.62	0.45 A	0.44 A	0.43 A
Genotype	AR043H	GT11	AR051H	AR630H	Danané
Harvest index	0.43 A	0.42 A	0.40 A	0.39 A	0.39 A
Genotype	AR624H	AR629H	AR597H	Kouiklonlé	Soungrouba
Harvest index	0.37 A	0.36 A	0.36 A	0.34 A	0.33 A
Genotype	Djoukemé	AR638H	Demamba	Palawan	Marigbè
Harvest index	0.30 A	0.28	0.26	0.26	0.13

Means not labelled with the letter A are significantly different from the control level mean.

3.6. Relationship between soil pH and performance components

Soil pH was not correlated with grain yield, straw yield and harvest index. However, fairly positive and highly significant correlation (0.34) was found between soil pH and grain moisture content.

3.7. Interference measurement among varieties

The hierarchical clustering of individuals showed three distinct clusters (figure 6). The first cluster was former uniquely by ARV, including Kouiklonlé, Danané, Djoukemé, Palawan, Demamba and Marigbè. The second cluster containing 9 varieties included WITA9, AR034H, AR051H, AR043H, AR629H, GT11, AR593H, AR601H and Koitè. The last cluster comprised AR630H, Soungrouba, AR624H, AR597H and AR638H (Figure 7). Moreover, the second cluster represented varieties grouped using yields: grains yield, straw yield and total dry matter. Cluster 1 and cluster 2 used moisture content and harvest index to group varieties, respectively.

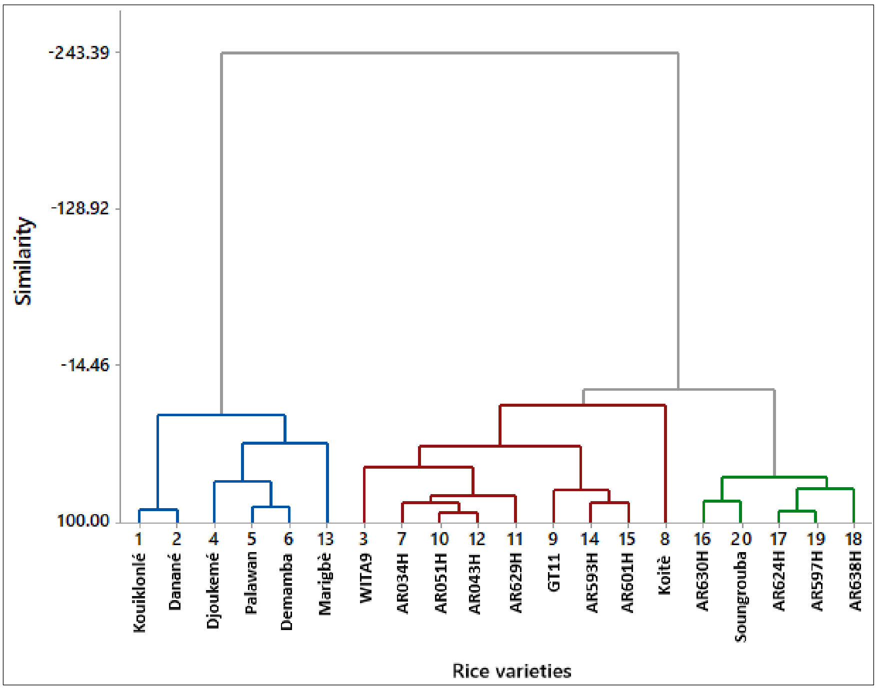

Figure 6 Hierarchical dendrogram showing clusters of rice varieties based on their similarity

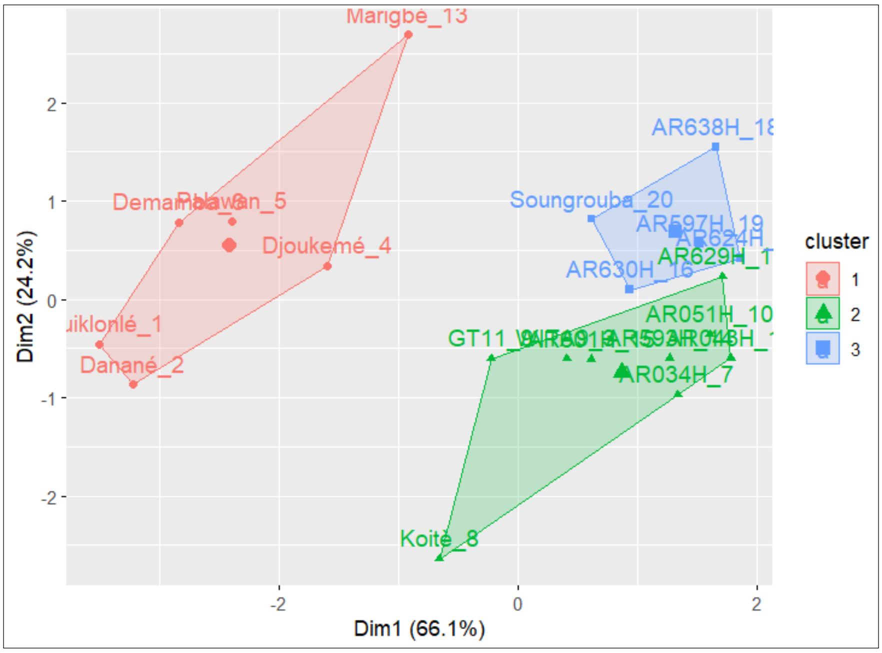

Figure 7 Cluster plot of improved and adopted rice varieties

4. Discussion

Modern improved varieties offer much higher yields, better grain quality (mostly fragrant rice), and sustainable production. The study revealed the performance of improved rice varieties (IRV) over adopted rice varieties (ARV), by comparing their means' values of grain and straw yields, grain moisture content and harvest index.

The harvest index observed in both type of crop were within the harvest index range of rice [22]. Even though there is an inconsistency in harvest index results in breeding, it helps to measure the difference between the potential and actual yield. As it is, high harvest index is now well entrenched as an essential plant characteristic for high crop yields [23, 24].

A crop yield will be higher when its harvest index will be higher. Moreover, harvest index does not depend only on genotype, but also on environmental conditions [25].

Improved rice potential yields were estimated to 10 t ha^{-1}. The observed yield gaps were 3.45 and 1.85 for the control WITA 9 and AR043H, respectively. Therefore, the control variety yield obtained was about 65.5 % of its potential yield, while the one of AR043H was 81.5 %. The sustainability of rice production is related to yield gap narrowing which requires integrated and holistic approaches [6]. Irrigated rice system reaching 70 – 80 % of yield potential is reasonable target for farmers who benefit of good management [26, 27, 28]. Moreover, high yield gap could be due nitrogen use efficiency, nitrogen fertilizer input, and cropping system [29]. In fact, previous research result showed positive effect of nitrogen application on WITA9's yield; 120 kg N ha^{-1} increased yield from 3.4 to 6.3 t ha^{-1} [18].

The cluster 2 represents varieties which had most of high grain and straw yields and total dry matter. High yielding and dry matter accumulation varieties adoption from this group of varieties could help to reduce mineral fertilizer application by retuning straw to the sol, to increase local rice yield where fertilizers acquirement is less or more difficult [30]

5. Conclusion

This study showed the importance of rice breeding in improving rice yield. However, increase rice production nationwide passes through vulgarization and adoption of new varieties. Further analyses, including nutritional values, fragrance, and organoleptic parameters are needed for adoption.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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