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Research Paper

Selection of high yielding rice (*Oryza sativa L.*) varieties, adapted to high altitudes and low temperatures in South Kivu, Eastern DR Congo

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ABSTRACT
The cultivation of rice (Oryza sativaL.) is a very important foodstuff in DR Congo. The rice basins located at high altitudes in South Kivu have the potential for production, despite this natural advantage; rice activity is struggling to develop. This work is part of this dynamic of testing the adaptability of improved rice genotypes adapted to the constraints of this environment. To contribute as little as possible to improving this activity, we selected 44 genotypes from the F10 generation (fixed lines) from the offspring of a cross between two parents adapted to high altitude ecologies. These 44 varieties were compared to a control variety (V046) for its performance in grain yield, number of tillers produced and plant height during the normal growing season A (September - January) and the off-season also called season B (February - June). In both seasons, 4 varieties (RPR2109, RPR2110 RPR2123 RPR2133) performed better than all other varieties. After careful analysis, we found that the RPR2110 variety was the best variety among the 4 productive varieties. This variety could be introduced into the national catalog and then be multiplied by national structures such as SENASEM and INERA and then be popularized by the SNV. It could also be used in the DRC's varietal improvement program.

Keywords: *Varietal adaptation, Rice, Agroecological Zone, South Kivu, High altitude, yield, cycle.*

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I. INTRODUCTION

In the Democratic Republic of Congo, rice plays an important role in the diet of the Congolese population but also in industry as a raw material in processing such as breweries and pharmaceutical products (Nsombo et al., 2012). The rice sector constitutes an axis of agricultural development in the country despite the fact that this crop only occupies seventh place after cassava, plantain, fruits, corn, peanuts and vegetables (Karboré, 2011). Rice is of major interest for the country's food security and self-sufficiency (John et al., 2020). Two types of rice cultivation exist today in the DRC with proportions of around 98% for rainfed rice and 2% for irrigated rice (Tshite&Lienge, 2016). Consequently, the country still cannot meet the needs of its population, more than 90% of rice consumed in the country is imported (Masiala, 2019). While the country has a suitable climate, diverse relief and large areas still unexploited which constitute great potential for practicing efficient rice cultivation (Walangululu et al., 2012).

South Kivu has several rice production areas. The most important are the territories of Walungu, Kalehe, Idjwi, Uvira, Shabunda, Mwenga and the territory of Fizi (Bashige, 2005). Despite these countless rice growing areas and its economic and nutritional importance, rice yields remain low in South Kivu (Bashige, 2005). Irrigated rice cultivation constitutes the most developed system in terms of the production achieved and the number of actors it involves (Mugunda&Habimana, 2019) while rainfed rice cultivation is less developed in this area (Bashige, 2005).

Poor access to quality seeds, not adapted to the conditions of different regions, constitutes the major cause of the drop in production due to the fact that the crops are not in their biotope (Tankoano, 2014). Therefore, to increase rice production in South Kivu, it is essential to apply the intensive rice growing system (SRI) based on the use of improved varieties and the reasonable contribution of mineral and/or organic fertilizers. Thus, the increase in rice production would follow mineral and/or organic fertilization with the use of improved varieties and would therefore constitute a strategic issue in the national policy to combat food insecurity (Gala et al., 2007).

Two major problems limit rice production in the rice-growing basins of South Kivu (consisting mainly of high altitude ecologies (>1000 meters), the lack of improved varieties with high yields and tolerance to low night temperatures. Indeed, in this study area; there are only traditional varieties with a long cycle (cycle length 5 to 6 months) and little tolerance to night temperatures which vary between 10 and 14 degrees Celsius. These low temperatures cause flower abortion and significantly reduce yields which were already very low. In view of the above, the selection of high-yielding and cold-tolerant rice varieties requires special attention.

The objective of this study is to contribute to the improvement of rice production through the selection of varieties adapted to high altitude ecologies and low temperatures in South Kivu.

II. MATERIALS AND METHODS

Study Area

This study was conducted in the Kabare Territory, more precisely in Kashusha. The Kabare Territory is located at 2° 30' South latitude and 28° 48' East Longitude, in the extreme east of the DR Congo, in the Province of South Kivu, on the western shores of Lake Kivu at a altitude varying between 1460 and 3000 m. The soils of Kabare derive from sedimentary, metamorphic, volcanic ash and recent alluvial rocks. The contribution of significant quantities of organic matter from the Kahuzi Biega National Park has significantly changed the ferralsols of the Kashusha lowland into Nitisols. The soils of the experimental site are generally heavy clayey or red-brown soils with light active acidity pH = 6.03.

Materials

44 varieties of rice were used in this study from Rwanda Agriculture Board (RAB). The local variety (V046) was used as a control because it is the most used by rice farmers. Table 1 represents the list of 45 rice varieties used in this study.

Table 1: List of varieties used in the study

N°	Noms/Numéro Identifiant	N°	Noms/Numéro Identifiant	N°	Noms/Numéro identifiant
1	RPR2101/RAB	16	RPR2116/RAB	31	RPR2131/RAB
2	RPR2102/RAB	17	RPR2117/RAB	32	RPR2132/RAB
3	RPR2103/RAB	18	RPR2118/RAB	33	RPR2133/RAB
4	RPR2104/RAB	19	RPR2119/RAB	34	RPR2134/RAB
5	RPR2105/RAB	20	RPR2120/RAB	35	RPR2135/RAB
6	RPR2106/RAB	21	RPR2121/RAB	36	RPR2136/RAB
7	RPR2107/RAB	22	RPR2122/RAB	37	RPR2137/RAB
8	RPR2108/RAB	23	RPR2123/RAB	38	RPR2138/RAB
9	RPR2109/RAB	24	RPR2124/RAB	39	RPR2139/RAB
10	RPR2110/RAB	25	RPR2125/RAB	40	RPR2140/RAB
11	RPR2111/RAB	26	RPR2126/RAB	41	RPR2141/RAB
12	RPR2112/RAB	27	RPR2127/RAB	42	RPR2142/RAB
13	RPR2113/RAB	28	RPR2128/RAB	43	RPR2143/RAB
14	RPR2114/RAB	29	RPR2129/RAB	44	RPR2144/RAB
15	RPR2115/RAB	30	RPR2130/RAB	45	V046 (Control)

Methods

After opening the land, preparing the soil and tracing the irrigation canals, two rice paddies of 25m² and 50cm deep were set up on a site of 50 m2, which allowed the formation of a dike to facilitate water control. . The water level was 10 cm high from transplantation until maturity.

A randomized complete block design with three repetitions was used (Figure 1).The land has been divided into 3 main plots which are repetitions. Each repetition included 45 elementary plots of 4 m x 4 m = 16 m^2 each and 0.5 m apart. The distance between repetitions was 2 m. In the elementary plots, the 21-day-old rice seedlings carefully removed from the germinator were transplanted at spacing's of 0.25cm x 0.25cm, which corresponded to 286 pockets per elementary plot. The trial was conducted two consecutive seasons in season A 2022 (September - January) then in season B 2023 (February - June).

Repetition 1

40	18	15	19	35	33	27	1	36
12	34	5	30	29	38	7	28	13
31	2	22	41	26	25	8	16	6
24	44	9	17	10	21	4	39	14
20	11	32	**45**	43	42	37	23	36

Repetition 2

39	43	13	16	38	5	36	**45**	44
33	41	40	34	27	3	37	18	31
7	21	2	14	42	35	25	20	10
17	23	32	24	26	12	11	28	22
6	15	8	29	9	4	30	2	19

Repetition 3

35	23	8	10	34	32	41	44	6
9	13	21	**45**	15	26	16	40	42
37	2	36	12	33	30	24	7	5
17	25	18	19	29	39	27	43	20
28	4	22	38	1	3	11	14	31

Legend: The numbers in the boxes correspond to the variety numbers; the number 45 corresponds to the control variety (V045)

Figure 1:Experimental design in randomized complete blocks with three (3) repetitions

The parameters observed in this study are air temperature (daytime and nighttime temperatures). It was recorded using a waterproof thermometer installed in the experimental site. Data were collected at the end of each development stage at the nursery level, at the tillering, flowering and maturity stages. The data was collected in the following way to obtain the minimum and maximum temperatures during germination; a thermometer was calibrated for 21 days from the day of placement in the nursery. For the tillering period, a thermometer was calibrated for 25 days and placed in the test on the day. At the germination; the thermometer was removed from the test. According the flowering period, a thermometer was calibrated for 14 days and placed in the trial on the day.At the tillering;the thermometer period was removed from the trial. For the maturity period, a thermometer was calibrated for 35 days and placed in the test on the day. At the flowering period; the thermometer was removed from the test (IRRI, 1996).

According the growth parameters, plant height (cm) of five plants were chosen randomly in each plot, and measured from the base of the plant to the end of the longest panicle using a graduated ruler. The number of tillers was counted on five plants chosen randomly in the plot. The number of days at 50% flowering is the number of days from transplantation until flowering where 50% of the plants in the plot have flowered. The duration of the vegetative cycle corresponds to the number of days from transplantation to flowering or 50% plus 35 days, which corresponds to complete maturity. We used this formula to calculate the yield.

$$\text{Yield } (kg/ha) = \frac{\text{Plot weight } (kg) * 10^4}{\text{Plot area}(m^2)}$$

Analysis of variance (ANOVA) was carried out with R software version 4.1.3, to compare the means between the quantitative variables.

III. RESULTS AND DISCUSSION

Results

Day and night temperatures during plant growth

Table 1 presents the daytime and nighttime air temperatures during the development stages of the rice varieties tested.

Table 1: Daytime and nighttime air temperatures during development stages

Development phase	**Season A**		**Season B**	
	Daytimeaverage (ºC)	**Nighttimeaverage (ºC)**	**Daytimeaverage (ºC)**	**Nighttimeaverage (ºC)**
Germination	31.3	18	33.1	13
Tilling	34	13.4	34.3	12.6
Flowering	31.9	14.9	34	13
Maturation	35.5	13.7	35.7	12.4
Means	33.2	15	34.3	12.8

Daytimeaverage temperatures were higher than the nighttime temperatures (33.2 ºC compared to 15.0 ºC in season A and 34.3 ºC compared to 12.8 ºC in season B). Also the average nighttime temperatures were lower in season B than in season A (12.8ºC in season B compared to 15.0ºC in season A) the opposite was observed concerning daytime temperatures (34.3ºC in season B compared to 33.2ºC in season A).

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Effect of seasons on the cycle, height and grain yield of the rice varieties tested

Table 2: Comparison of the effect of the seasons on the observed parameters

Season	Cycle (Days)	Number oftillers	Height(cm)	Yield (Kg/ha)
A	133a	21a	89,12a	1668.94a
B	136a	16b	91,05a	797.96b
LSD	-	2.11	-	343.49
CV	10.8 %	5.1 %	63.7 %	78.4 %

The statistical analysis result shows (Table 2) that planting in season A or season B did not affect either the cycle or the height of the plants of the rice varieties tested. However, the number of tillers produced and grain yield were significantly affected by seasons. Indeed, a greater number of tillers were produced in season A, the same is true for grain production.

Averages of parameters measured during seasons A and B

The results relating to the vegetative parameters are presented in Table 3. It summarizes the averages of the vegetative parameters and yield studied for all the varieties.

Table 3: The vegetative cycle, plant height, number of tillers and grain yield of rice varieties measured during the 2 seasons

Varieties	Cycle (Days)	Number of tillers	Height (cm)	Yield(kg/ha)
V046	150	11	90.2	3425.00
RPR2101/RAB	132	18	81.4	1537.50
RPR2102/RAB	160	21	91.2	937.50
RPR2103/RAB	112	19	93.2	962.50
RPR2104/RAB	149	29	77.4	1300.00
RPR2105/RAB	135	24	97.8	1462.50
RPR2106/RAB	130	21	87.4	1187.50
RPR2107/RAB	135	23	95.0	2750.00
RPR2108/RAB	134	20	87.4	1462.50
RPR2109/RAB	131	21	86.6	6187.50
RPR2110/RAB	136	28	76.0	6512.00
RPR2111/RAB	119	22	88.4	1300.00
RPR2112/RAB	136	23	69.8	2500,00
RPR2113/RAB	119	16	81.8	162.50
RPR2114/RAB	112	20	91.0	962.50
RPR2115/RAB	140	13	87.2	450,00
RPR2116/RAB	133	18	89.2	750.00
RPR2117/RAB	161	31	83.2	1775.00
RPR2118/RAB	107	29	90.4	1175.00
RPR2119/RAB	140	20	87.2	4487.50
RPR2120/RAB	116	13	109.0	1600.00
RPR2121/RAB	136	18	69.6	1412.50
RPR2122/RAB	112	15	100.4	937.50
RPR2123/RAB	135	23	100.8	5900.00
RPR2124/RAB	119	12	93.8	762.50
RPR2125/RAB	147	27	77.0	1000.00
RPR2126/RAB	136	19	79.8	612.50
RPR2127/RAB	136	20	63.6	800.00
RPR2128/RAB	136	19	102.2	400.00
RPR2129/RAB	136	21	98.6	512.50
RPR2130/RAB	131	25	87.2	2200.00
RPR2131/RAB	140	18	79.2	375.00
RPR2132/RAB	140	10	78.6	437.50
RPR2133/RAB	107	17	89.8	4775.00
RPR2134/RAB	136	23	102.2	1712.50

RPR2135/RAB	140	23	84.6	737.50
RPR2136/RAB	140	21	75.2	712.50
RPR2137/RAB	147	29	86.6	1862.50
RPR2138/RAB	147	28	75.4	1737.50
RPR2139/RAB	107	24	78.2	575.00
RPR2140/RAB	136	24	81.8	1175.00
RPR2141/RAB	137	16	84.6	775.00
RPR2142/RAB	106	20	95.8	1512.50
RPR2144/RAB	142	19	85.8	412.50
RPR2144/RAB	134	23	87.4	1925.00

The varieties *RPR2109*, *RPR2110*, *RPR2123* and *RPR2133* stood out. They presented a short cycle, a higher yield compared to all the other varieties, superior, more than the local variety V046 (Control). Regarding the vegetative cycle, the cycle varied between 107 and 136 days, with an average of 135 days. As for performance, we see the same thing. The yield ofthese varieties *RPR209*, *RPR2110*, *RPR2123, and RPR2133*varied between 5000 and 6000 Kg/ha, higher than that of the controlvariety (V046). The former is around 3000 Kg/ha.

Comparison of grain yields produced during season A and B

Figure 2 compares the grain yields of all 45 varieties studied. The varieties *RPR2109*, *RPR2110*, *RPR2123* and *RPR2133* produced more in season A and B than all the other varieties including the control variety (V046).

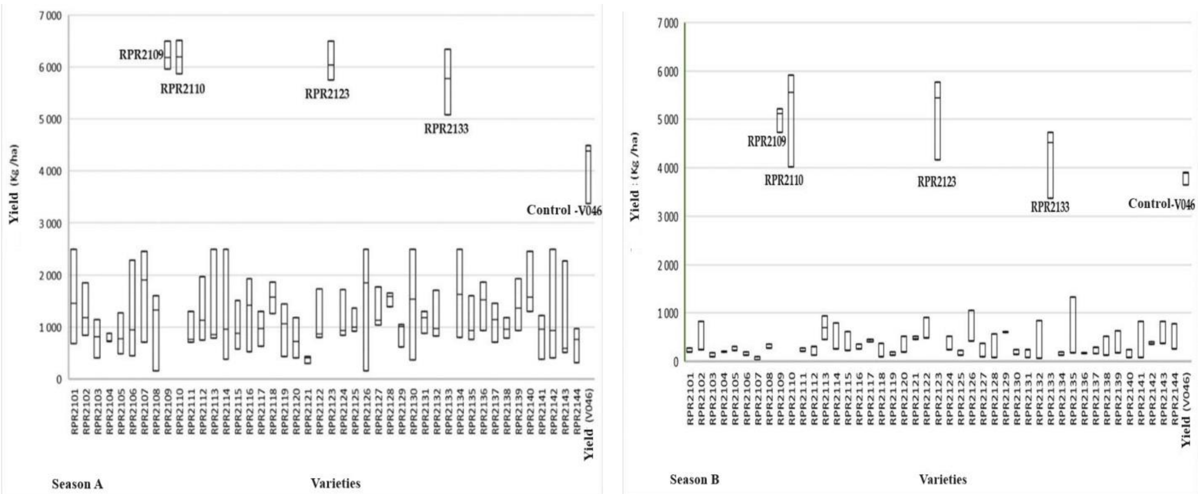

Figure 2: Comparison of variety grain yields in season A and B

Comparison of the best varieties

The cycleduration varied depending on the variety. The variety *RPR2133* has a short cycle (114 and 115 days).For those varieties *RPR2109, RPR2110,* and *RPR2123*, the cycle varies between 130 and 135 days, and the control variety (*V046*) the cycle beyond of 150 days. Analysis of variance(P = 0.000471) showed a highly significant difference between varieties (Figure 3).

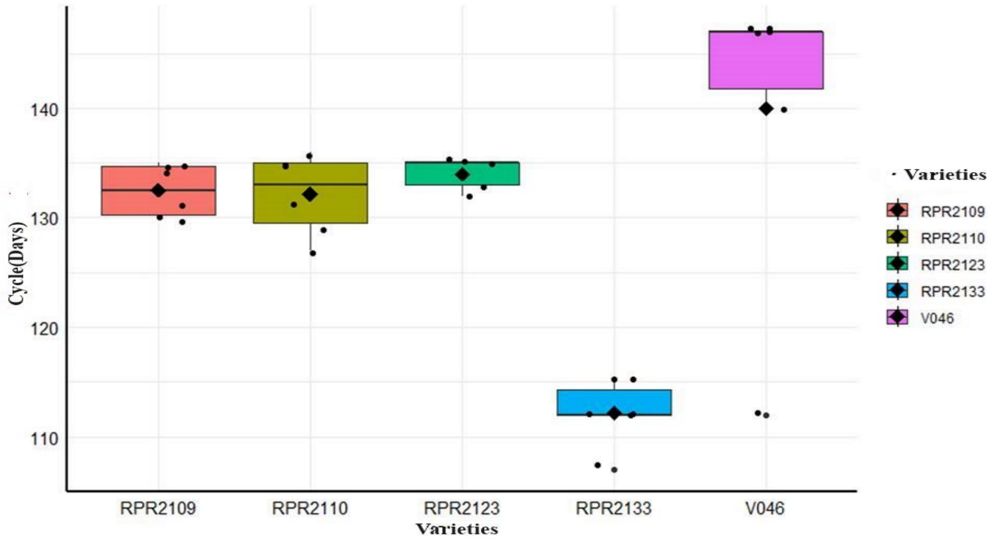

Figure 3 :Comparison of the cycle duration of the best varieties

Regarding the plant height, there were no differences between other varieties compared to the control variety (Figure 4).The height did not vary very significantly between the varieties, however the variety *RPR2133* presents a slight difference (P = 0.413).

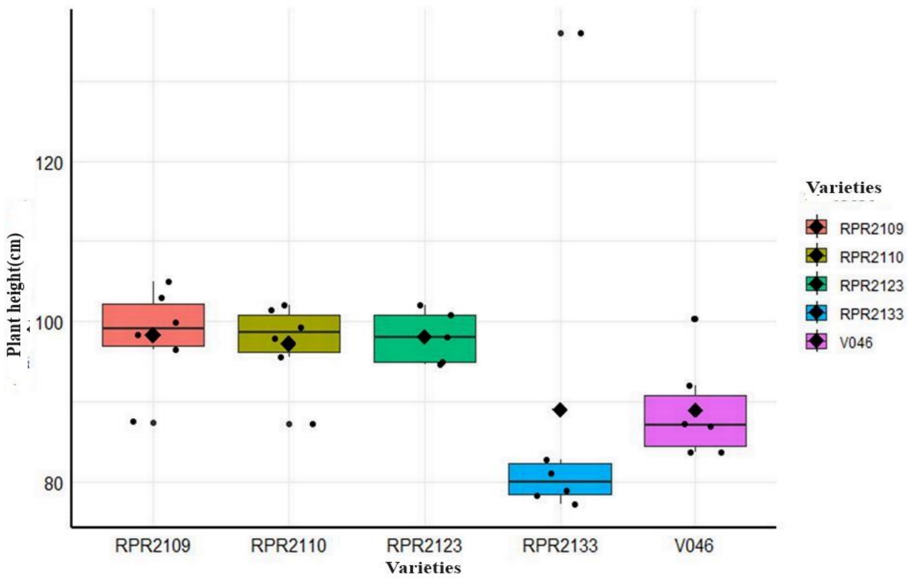

Figure 4: Comparison of plant height of the best varieties

The number of tillers varied depending on the varieties (Figure 5). The *RPR2110* variety presented a large number of tillers (25 tillers), followed by the *RPR2123* variety (23 tillers), and again with the *RPR2133* variety (20 tillers). The *RPR2109* variety presented 10 tillers per foot which approximates the control variety (V046).

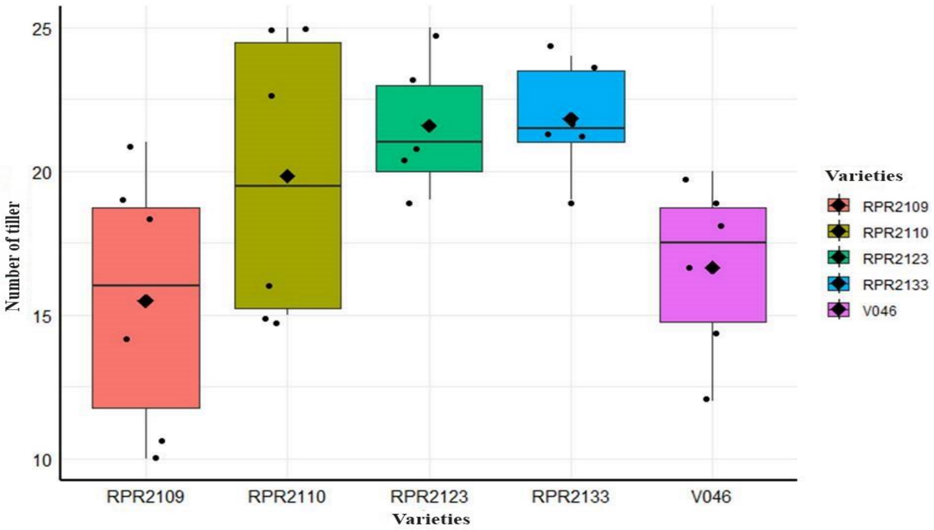

Figure 6: Comparison of tiller number production of the best varieties

The yield varied depending on the variety because there's a highly significant difference (4.71e-06 ***) at P<0.05. The varieties *RPR2109, RPR2110*, and *RPR2123*have a high yield. They yield varies between 5500 and 6000 kg/ha. The variety *RPR2133* presents a yield between 4500 and 5000 kg, and the *V046* (control variety) between 4000 and 4500 Kg.

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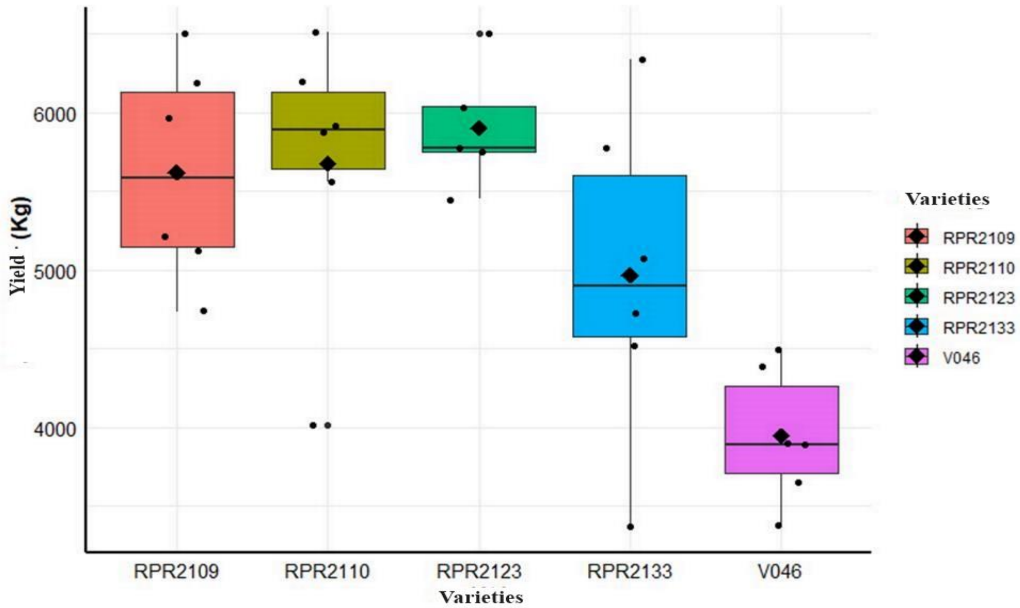

Figure 7:Comparison of grain yields of the best varieties

IV. Discussion

Variations in daytime and nighttime temperatures were also observed, rice growth parameters (number of tillers and plant height) and on grain yield were measured. The trends of variations in daytime and nighttime temperatures obtained during our experiments are similar to those observed by Schalbroeck in 2001.In our study, the essential adaptation criteria retained were yields and cycles (Patrice et al., 2022).

The results of the height analysis show that all varieties used in this study are less susceptible to lodging. According to Futakuchi et al. (2018), a rice variety is susceptible to lodging when its height reaches or exceeds 150 cm.

Our results showed that grain yields are higher in season A (average production 1668.94 kg in season A compared to 797.96 kg in season B). A poor performance recorded in season B would be due to low night temperatures. The depressive effect of grain yield linked to extreme low temperatures was described by Michel et al. (2019). These results are also consistent with those described by Traoré (2015).

The phenological differences of the varieties studied despite being descendants of the same parents are the results of the recombination of genes during meiosis. Several authors such as Nouar et al.(2010), Benmahammed et al.(2010) have described this fact which is common among all bisexual beings. It emerges from our study that the *RPR2110* variety produced the highest yield, thus demonstrating its tolerance to environmental constraints. This variety could be the most suitable for rice farmers in Kashusha in South Kivu.

V. CONCLUSION

The resultat of the presentstudy showed the performance of rice in the agroecological conditions of Kashusha in the territory of Kabare, province of South Kivu varied depending on the varieties.The varieties did not behave in the same way in the agroecological zone of Kashusha. Four varieties (*RPR2109, RPR2133, RPR2110,* and *RPR2123*) responded better to the agro-ecological conditions of Kashusha. Among the four varieties, the *RPR2110* variety responded best in terms of yield and its short cycle to the agro-ecological conditions of Kashusha.

The adaptation test in other agroecological zones of the province as well as an evaluation of their response to different agricultural practices such as fertilization, disease resistance and organoleptic quality are recommended for a good choice of the variety to be released. in the agroecological zones of the province..

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