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Grouping rice varieties in Morocco based on key agronomic traits: A PCA and HCA approach

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Abstract: The identification and classification of rice varieties based on key agronomic traits are essential for enhancing productivity and adaptability in diverse growing environments. This study focused on 18 rice varieties cultivated in Morocco, comprising 14 Korea-Africa Food and Agriculture Cooperation Initiative (KAFACI) lines, three National Institute of Agricultural Research (Fr.: Institut national de la recherche agronomique – INRA) Morocco varieties, and a control cultivar, 'Lagostino', widely used by Moroccan farmers. The experiment was conducted at the Sidi Allah Tazi Experimental Domain (Fr.: Domaine Expérimental de Sidi Allal Tazi) using a randomised complete block design (RCBD) with three replications. Hierarchical cluster analysis (HCA) and principal component analysis (PCA) were utilised to group varieties based on significant agronomic traits. The analysis revealed four distinct clusters. Cluster 1, including 'KF190066', showed high values for plant height, 1000-seed weight, and panicle length. Cluster 2, represented by the control cultivar 'Lagostino', was characterised by an earlier heading and fewer panicles per plant. Cluster 3, including 'KF190064' and 'KF190065', displayed the highest straw and seed yields despite shorter panicles. Cluster 4, comprising 'Ka WS 9294292', 'Nachat' (INRA Morocco), 'CB MS11', and 'Hayat' (INRA Morocco), exhibited extended heading and maturity durations, alongside higher tiller and panicle counts per plant. These findings highlight the agronomic diversity potential of rice varieties in Morocco, providing critical insights for breeding programs. The identification of superior varieties, such as 'KF190064', 'Hayat', and 'KF190066', reinforces their potential for boosting rice production and sustainability under Morocco's agro-climatic conditions.

Keywords: agro-climatic, agronomic traits, HCA, KAFACI, Morocco, PCA, rice cultivars

INTRODUCTION

Rice (*Oryza sativa* L.) is one of the most important staple crops globally, providing food security for more than half of the world's population. In Morocco, rice cultivation is a significant contributor to the agricultural economy, particularly in regions like the Gharb, where the climatic conditions are favourable for paddy fields. However, the country's rice sector faces several challenges, including unpredictable environmental conditions, increasing water scarcity, and the prevalence of diseases such as rice blast caused by *Magnaporthe oryzae* (Elwahab *et al.*, 2023). To overcome these obstacles and ensure sustainable production, it is crucial to develop high-yielding, disease-resistant, and climate-adapted rice varieties.

Currently, the varietal profile in Morocco is moderately diversified, including round, medium, and long-grain varieties. Despite the presence of 17 Moroccan rice cultivars selected by the National Institute of Agronomic Research (Fr.: National de la Recherche Agronomique – INRA) between 1987 and 2001, most farmers rely on imported seeds. Reviving these local varieties and promoting new national varieties is essential for building a diverse genetic heritage and reducing reliance on foreign imports. Such efforts would not only decrease production costs but also align with the national agricultural strategy's objectives. However, many constraints continue to hinder this sector's development (Elwahab *et al*., 2024).

Agronomic characterisation is a fundamental step in understanding the genetic diversity of rice varieties and optimising their performance in diverse environments. It is standard procedure to use morpho-agronomic metrics, such as plant height, number of tillers, panicle length, panicle fertility, and 1000-grain weight, to assess the production capacity and adaptation of genotypes. A study looked at the genetic diversity, heritability, and genetic gain for yield and its components in rice to show how important these factors are for varietal selection (Tuhina-Khatun *et al*., 2015). These characteristics are especially essential for breeding efforts that seek to increase grain quality, disease resistance, and drought tolerance. To create cultivars that are suited to biotic restrictions and climate change, for instance, genetic variety is seen as a crucial tactic (Huang *et al*., 2010).

In recent years, Morocco has introduced several rice genotypes through initiatives like the Korea-Africa Food and Agriculture Cooperation Initiative (KAFACI), alongside existing local and regional varieties. These introductions provide an invaluable genetic pool for breeding programs. Understanding the agro-morphological diversity of these varieties can help identify genotypes with superior performance and adaptability, particularly under the constraints of Moroccan rice cultivation, such as water scarcity and climatic variability (Elwahab *et al*., 2024).

Recent advances in statistical tools like hierarchical cluster analysis (HCA) and principal component analysis (PCA) have proven invaluable for grouping and characterising rice genotypes based on multiple traits (Choudhary *et al*., 2022). These techniques have been widely used to explore genetic diversity, identify superior lines, and support targeted breeding strategies (Maji and Shaibu, 2012). For example, research conducted in West African countries, including Senegal, has demonstrated the effectiveness of these approaches in identifying varieties with higher yields, drought tolerance, and disease resistance (Adjah *et al*., 2022).

The present study aims to characterise and group rice varieties in Morocco based on key agronomic traits using PCA and HCA. This approach not only sheds light on the phenotypic diversity of the studied varieties but also provides breeders with actionable insights for selecting high-performing genotypes tailored to local agroecological conditions. By leveraging advanced statistical tools, this study contributes to ongoing efforts to improve rice production and sustainability in Morocco.

MATERIALS AND METHODS

STUDY AREA

The study area includes the Gharb Plain, which stretches along the Atlantic coast between 34° and 34°45' N. It covers a vast hydrogeographic region of 7,500 km^2. The Gharb Plain is famous for its diversity of soils. Starting from Oued Sebou and moving inland, we encounter the soils of Dehs, Shots and Merjas, each characterised by its own characteristics. The research focuses specifically on the Sidi Allal Tazi region, located about 57 km from Kenitra (Fig. 1). In this region, rice is grown on grey alluvial soils. These soils are mainly clay, typically low in humus, deficient

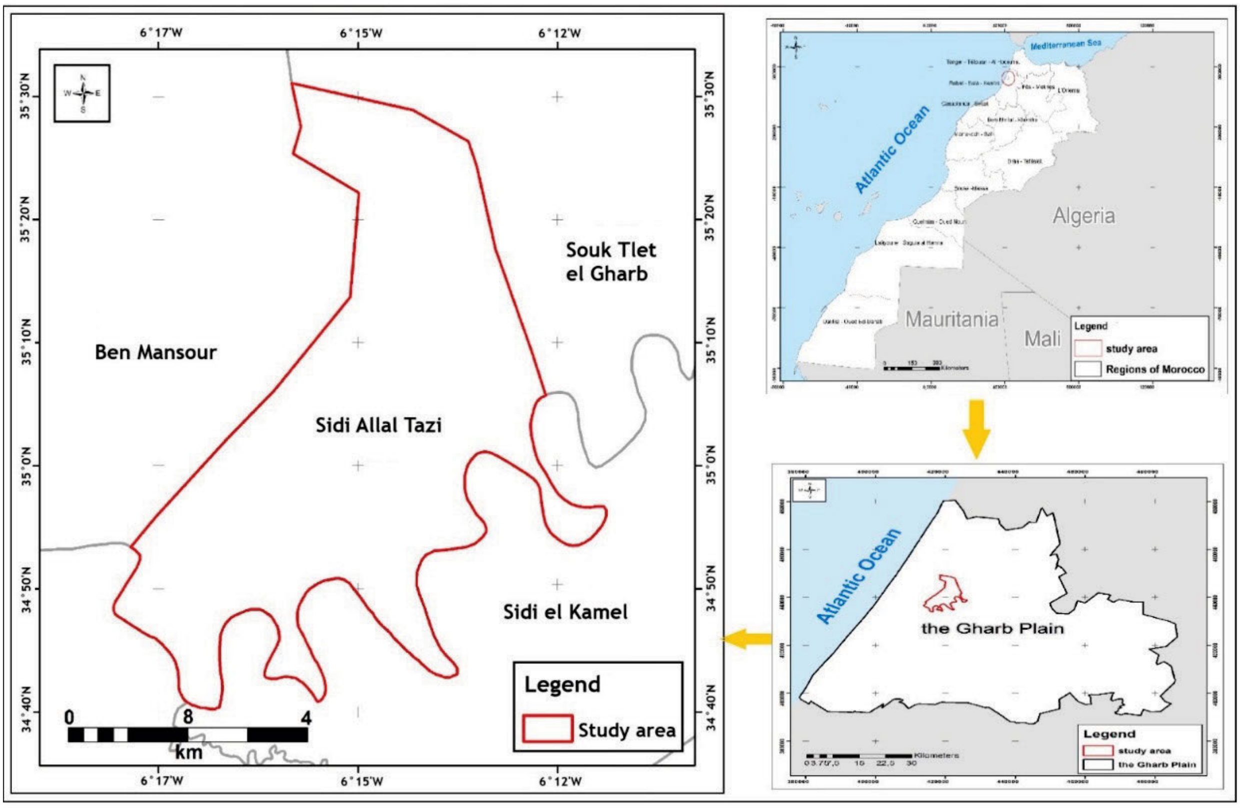

Fig. 1. Geographic map of study area; source: own elaboration

in phosphoric acid and often low in nitrogen. They have a slightly alkaline pH. The climate of this region is Mediterranean and offers important water resources from the Sebou River, its tributaries, the Merjas and groundwater.

STUDY MATERIALS

The plant material consisted of 14 Korea-Africa Food and Agriculture Cooperation Initiative (KAFACI) lines chosen from 100 lines introduced from the Africa Rice Center in Saint-Louis, Senegal, and tested in 2020, along with three National Institute of Agronomic Research (INRA) Morocco varieties. The control cultivar, used by 'Lagoustino' farmers (a foreign cultivar used in Morocco), was added to these lines. The trial focused on a demonstration test (National Performance Test) installed at a farmer's field. It was conducted under the supervision of the National Inter-professional Rice Federation in collaboration with INRA. This trial involved five KAFACI lines selected in 2019 and 2020, along with three INRA Morocco varieties (Tab. 1).

STUDY METHODS

Land preparation and experimental design

The experiment was conducted in the Gharb region, known for its hydromorphic Vertisols, which are well-suited for rice cultivation except in areas that are too draining or too compact (FAO, 2003). Soil preparation began in May with mechanical operations, including deep grinding, coating, and tracing seed lines. Trench construction varied in size, with the largest measuring of 4 × 4 × 0.2 m to facilitate drainage and water distribution. Canals and drains were built to bring water to the plots and ensure effective drainage.

The experimental design consisted of 4 × 0.2 m plots with four rows, 0.2 m row spacing, and 0.2 m plant spacing, covering a total area of 3.2 m^2 per plot, with 80 plants per plot. Additional plots measured 5 m long rows with 25 plants per row, separated by 0.3 m. A randomised complete block design (RCBD) was applied with three replications.

Soil and climatic conditions

The soil in the Gharb region, characterised by Vertisols and hydromorphic Vertisols, has an organic matter concentration ranging from 0.74% to 2.88%, a pH of 6.75 to 8.57, and a total limestone content varying from 0 to 49% (Miège, 1951; Zidane *et al.*, 2010). Surface water NaCl concentrations range from 0.2 to 1.7 $g \cdot dm^{-3}$, and pore water NaCl concentrations vary from 0.25 to 3 $g \cdot dm^{-3}$ (El Blidi *et al.*, 2006). Climatic conditions were favourable for rice cultivation, with annual rainfall averaging between 450 and 600 mm, concentrated mostly between October and April. During the experiment, temperatures ranged from an average daily 11°C in winter to 27°C in summer, and the rice-growing season from mid-April to late September provided an ideal climate. The Gharb and Loukkos regions, contributing significantly to Moroccan rice production, experienced favourable rainfall during the planting season, complemented by irrigation. In marketing year (MY) 2024/25, rice cultivation covered approximately 8,250 ha, with a production estimate of 45,500 Tg, marking a slight increase from the previous year (Fig. 2).

Table 1. Reference of lines used in 18 cultivated rice varieties

Line	Serial No.	Entry No.	Pedigree
1	'KF18044'	2018 ws (8220056)	SR35357F1-1-3-4-1
2	'KF18045'	2018 ws (8220057)	SR35357F1-1-3-4-1
3	'KF18046'	2018 ws (8220058)	SR35357F1-1-3-4-1
4	'Ka WS 9294292'	2019 ws	–
5	'CB MS11'	2019 ws	–
6	'Nachat' (INRA Morocco)	–	–
7	'Hayat' (INRA Morocco)	–	–
8	'Samar' (INRA Morocco)	–	–
9	'KF190052'	2019 ws(9220038)	SR34574-HB3565-285
10	'KF190052'	2019 ws(9220039)	SR34574-HB3565-290
11	'KF190063'	2019 ws(9220061)	SR35266-HB3580-110
12	'KF190064'	2019 ws(9220065)	SR35285-HB3573-48
13	'KF190065'	2019 ws(9220066)	SR35285-HB3573-72
14	'KF190066'	2019 ws(9220067)	SR35285-HB3573-75
15	'KF190112'	2019 ws(9230269)	HR32054F1-2-17-1-3-3
16	'KF190114'	2019 ws(9230265)	HR32054F1-2-17-1-3-3
17	'KF190136'	2019 ws(9230343)	HR32054F1-2-17-1-3-3
18	control ('Lagustino')	–	–

Source: own elaboration.

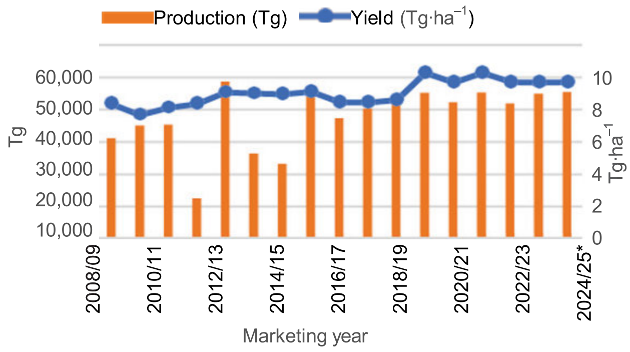

Fig. 2. Morocco's rice production and yield; * = estimated data for the 2024/25 season; source: own elaboration based on USDA (2024)

Fertilisation and planting

The first application of 400 kg·ha^{-1} of 10–30–10 NPK fertiliser was made on May 18, 2021 as a baseline. Urea fertiliser (125 kg N·ha^{-1}, 46%) was applied twice on July 7 and July 26, 2021. Chemical weeding was performed twice: on June 24, 2021, using 1 dm^3·ha^{-1} of Rainbow and on September 11, 2021, using Agroxone. Additional insecticide and fungicide treatments were applied on July 19 and August 9, 2021. Manual weeding was occasionally conducted during the trials.

Irrigation and drainage

Rice cultivation in Morocco heavily relies on irrigation. In this study, water was sourced from rivers and distributed via constructed canals and trenches to maintain submersion watering. The drainage system was effective in regulating water flow and ensuring optimal soil moisture for growth.

Experimental setup and transplantation

A nursery was established near the trial site to prepare seedlings. The plots were initially watered for two weeks before a second ploughing to facilitate planting. Transplanting occurred on July 1, 2021, two days after the first fertiliser application. Eighteen-day-old seedlings were transplanted at a rate of two seedlings per pocket with a spacing of 0.2 × 0.2 m (Photo 1). The KAFACI lines used were selected from the previous year's trials.

Photo 1. Planting and sowing of Kafaci rice lines (phot.: *F. Elwahab*)

DATA COLLECTION

Agro-morphological data were collected from each rice cultivar based on several key parameters. Days to heading (*DH*) refers to the number of days from seeding until the first visible panicle, while days to maturity (*DM*) indicates the time taken from seeding to physiological maturity. Plant height was measured in centimetres, from the base of the plant to the tip of the tallest panicle. The number of tillers per plant (*NTP*) represents the count of productive tillers per plant, and the number of panicles per plant (*NPP*) reflects the total panicles produced by each plant. Length of panicle (*LP*) was determined as the average length of the panicles, measured in centimetres. The weight of 1000 seeds (*WTS*) was calculated by weighing 1000 grains for each cultivar. The fertility rate (%) was derived as the percentage of filled grains to the total grains per panicle. Lastly, the number of grains per panicle was measured as the average number of grains produced per panicle. These parameters provide a comprehensive understanding of the growth and yield characteristics of each rice cultivar.

STATISTICAL ANALYSIS

The agro-morphological data of 18 cultivated rice varieties were analysed using R Studio (version 4.4.0). A one-way analysis of variance (ANOVA) was performed to assess significant differences in traits such as plant height (cm), *NTP*, *NPP*, *LP* (cm), *WTS* (g), *DH* (d), *DM* (d), seed yield (Mg·ha^{-1}), and straw yield (Mg·ha^{-1}) among the varieties, with significance determined at a p-value < 0.05. To compare the means and identify statistically significant differences, Duncan's multiple range test (DMRT) was used, where varieties with different letters indicated significant differences in their means for each trait. Descriptive statistics (mean and standard deviation) were also calculated to summarise the data and provide insight into the variation within and between varieties. In addition to ANOVA and DMRT, two multivariate statistical methods were applied. hierarchical cluster analysis (HCA), using Euclidean distance and the Ward method, grouped the varieties based on similarities in traits such as plant height, tillers, and *WTS*. Principal component analysis (PCA) was conducted to reduce data dimensionality and identify key traits driving variability. The first two principal components explained a significant portion of the variance, and a biplot was used to visualise the distribution of the varieties and their trait influences.

RESULTS

EVALUATION OF AGRONOMIC TRAITS

The results in Table S1 offer insights into the agronomic performance of 18 rice varieties based on multiple traits, providing valuable data for breeders and researchers to identify superior varieties for specific objectives like yield improvement or adaptation to Moroccan growing conditions.

The analysis of key agronomic traits among the studied rice varieties highlights significant variability, offering insights for targeted breeding and cultivation strategies.

There are notable differences between cultivated varieties with respect to *H* (cm). The tallest plants were observed in 'KF190066', with an average height of 159.33 cm, making it well-suited for biomass production. However, its height could increase susceptibility to lodging under certain conditions. On the other hand, the control ('Lagustino') was the smallest at 89.00 ±2.7 cm, while the cultivars 'KF18046' (117.56 ±3.1 cm), 'Ka WS 9294292' (110.44 ±2.9 cm), and 'KF190114' (114.66 ±2.6 cm) reached the highest heights. Potential yield and flow resistance may be impacted by this variability.

Tillering capacity, a critical determinant of productivity, varied notably among the varieties. High tillering capacities were recorded in 'KF190064' and 'CB MS11', with 32.89 and 32.44 tillers per plant, respectively, enhancing their yield potential. Conversely, in 'KF190066' the lowest tillering capacity (23.11 tillers) was exhibited, which might limit its productivity in less favourable conditions.

The highest number of panicles per plant (*NPP*) (31.00) was recorded in 'KF190064', suggesting its strong seed productivity potential. The control cultivar, 'Lagostino', had the lowest panicle count (20.33), indicating relatively lower productivity. The longest length of panicle (*LP*) was observed in 'KF190066' (32.74 cm), a trait associated with high grain yield potential. On the other hand, the shortest *LP* was recorded in 'KF190136' (16.90 cm), which could negatively impact grain yield.

Seed weight, an essential indicator of grain quality, was highest in 'KF190066' (35.25 g), signifying its market and consumer appeal. In contrast, 'Ka WS 9294292' exhibited the lowest seed weight (22.83 g), which might reduce its attractiveness for markets prioritising larger grains. Varieties differed significantly in their maturation timelines. 'Lagostino' was the earliest maturing cultivar, with the shortest days to heading (*DH*) (87.33 days) and maturity (*DM*) (132.00 days), making it ideal for regions requiring early-maturing crops. On the other hand, 'Hayat' (INRA – National Institute of Agricultural Research – Morocco) and 'Nachat' (INRA Morocco) exhibited longer maturity periods (157.00 days), potentially advantageous in regions with extended growing seasons. The cultivar 'KF18046' showed notable earliness with an early maturity observation at 96 days and an average maturity duration of 137.67 days, which is favourable for short-cycle areas. However, the cultivar 'Samar' (INRA Morocco), exhibited headier times of up to 99–139 days. However, the control ('Lagustino') shows poor performance on all evaluated parameters: a reduced number of tillers (*NTP*) and panicles (*NPP*), limited height (*H*), low weight of 1000 seeds (*WTS*), low grain yield, and light straw weight. These data indicate a limited adaptability or negligible agronomic value, which could explain its exclusion from the next selection test series. The observed variation in cycle duration (from 96 to 117 days for heading) provides an appropriate response to various agro-ecological requirements, ranging from early varieties intended for water-stressed regions to late high-yield varieties in irrigated areas. The results indicate performances that vary depending on the traits examined.

The cultivar 'KF190064' emerged as the top-performing in terms of seed yield, achieving 53.11 $Mg \cdot ha^{-1}$, highlighting its significant potential for grain production. By contrast, 'KF190052' and 'KF190061' showed the lowest seed yields (39.33 $Mg \cdot ha^{-1}$), indicating limited adaptability or productivity under the studied conditions. Straw yield, important for dual-purpose systems where straw is used as fodder, was highest in 'KF190064' and 'KF190065', with yields of 41.01 $Mg \cdot ha^{-1}$ and 40.36 $Mg \cdot ha^{-1}$, respectively. Conversely, in 'Ka WS 9294292' the lowest straw yield was observed (29.90 $Mg \cdot ha^{-1}$), limiting its utility in systems where straw plays a crucial role. This comprehensive evaluation underscores the diverse agronomic potential among the studied rice varieties; it highlights candidates like 'KF190064' for grain yield and dual-purpose uses, while others, such as 'Lagostino', show promise for early maturity in specific agro-climatic zones. These findings contribute valuable information for breeding programs and sustainable rice production strategies in Morocco.

HIERARCHICAL CLUSTER ANALYSIS

The results from the hierarchical cluster analysis (HCA) conducted on the studied rice varieties were obtained. The main objective of these analyses is to characterise the varieties based on their morphological traits and yield, in order to identify distinct groups and understand the relationships between the different characteristics. The HCA reveals four distinct classes of individuals, each characterised by specific variable profiles (Fig. 3): class 1 includes varieties such as 'KF190066', characterised by high values for plant height, *WTS*, and *LP*. These traits indicate that these varieties are robust with favourable seed size. Class 2, represented by varieties like control, 'Lagostino', is distinguished by low values for days from seeding to heading and *NPP*. This suggests quicker maturation and lower panicle production, potentially reflecting specific adaptation strategies or different growth patterns. Class 3 comprises varieties such as 'KF190064', 'KF190065', and 'KF190136', which show high straw and seed yields but shorter panicles. These varieties exhibit strong yield potential but with relatively shorter *LP*, which may affect seed quality or harvesting practices. Class 4 includes varieties like 'Ka WS 9294292', 'CB MS11', 'Nachat' (INRA Morocco), and 'Hayat' (INRA Morocco). This group is characterised by high values for days from seeding to heading and maturity, *NPP*, and number of tillers per plant (*NTP*), but with lower straw yields. These varieties display longer growth periods and higher panicle and tiller production, although they have lower straw yields.

PRINCIPAL COMPONENT ANALYSIS

The principal component analysis (PCA) provides complementary insights into the variables influencing the distribution of the rice varieties. Dimension 1 distinguishes between varieties such as

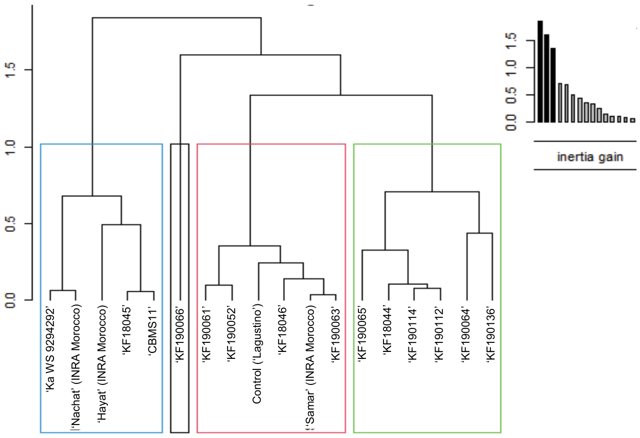

Fig. 3. Hierarchical classification of different rice accessions based on agro-morphological parameters; source: own study

'Ka WS 9294292', 'Nachat' (INRA Morocco), 'CB MS11', and 'Hayat' (INRA Morocco) (located on the right side of Fig. 4) and varieties like 'KF190066', control ('Lagostino'), and 'KF190065' (located on the left side of Fig. 4). The varieties on the right exhibit high positive coordinates and are characterised by elevated values for the number of days from seeding to heading, days from seeding to maturity, *NTP*, and *NPP*, with low straw yield. In contrast, the varieties on the left show negative coordinates and high values for plant height, *WTS*, and *LP*, with low values for days from seeding to heading and *NPP*. This dimension highlights a contrast between varieties with long growth periods and high panicle production versus those with high plant height and seed weight but faster maturation. Dimension 2 contrasts varieties such as 'Ka WS 9294292', 'Nachat' (INRA Morocco), 'CB MS11', and 'Hayat' (INRA Morocco) (located at the top of Fig. 4) with varieties like 'KF190136', control ('Lagostino'), and 'KF190065' (located at the bottom of Fig. 4). The varieties at the top display positive coordinates with high values for days from seeding to heading and maturity, *NTP*, and *NPP*, but have low straw yield. In contrast, the varieties at the bottom show negative coordinates with low values for days from seeding to heading, *NTP*, and *NPP*, as well as low straw yield, with 'KF190136' also exhibiting a shorter *LP*. This dimension underscores a distinction between varieties with late maturation and high production versus those with early maturation and opposing characteristics.

The variable contributions to the construction of these dimensions are illustrated in Figure 5. The variables most significantly represented on the plan are named, providing a clear view of their influence on the PCA results.

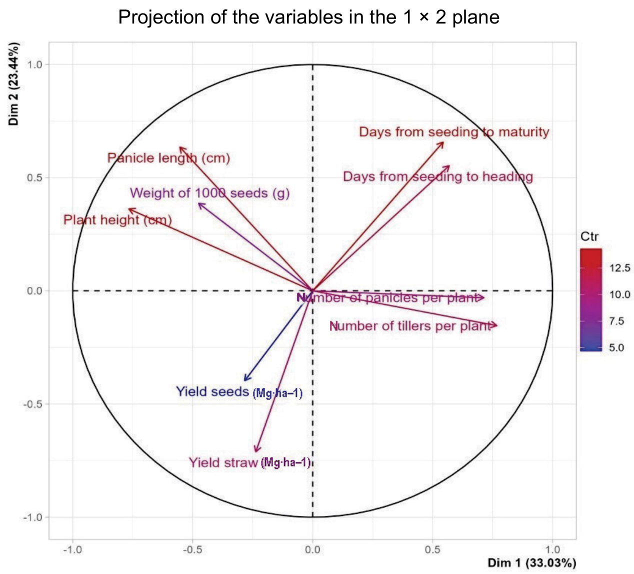

Fig. 5. Variable graph (principal component analysis) – the variables with the names are those best represented on the plan; Ctr = contribution; source: own study

DISCUSSION

In this study, a comprehensive analysis of 18 cultivated rice varieties revealed significant variability in key agronomic traits, highlighting the critical role that agro-morphological characterisation plays in the success of varietal development initiatives, which is consistent with Bello *et al.* (2018), who emphasised that understanding of plant genetic resources is essential for producing high-yield, high-quality cultivars. This study looked at several important agro-morphological traits, including plant height (*H*), panicle length (*LP*), number of tillers per plant (*NTP*), number of panicles per plant (*NTP*), seed-to-maturity cycles, and weight of 1,000 grains (*WTS*). These characteristics serve as the cornerstone of breeding initiatives and are essential for evaluating the potential of rice cultivars in various circumstances (Elwahab *et al.*, 2025). This is consistent with findings from earlier research, including that of Kalaitzidis *et al.* (2025), who emphasised the significance of high panicle counts and robust tillering in attaining ideal rice yields. Similarly, in 'Hayat' (INRA – National Institute of Agricultural Research – Morocco) and 'KF190066' excellent performance in both seed and straw yields was demonstrated, reinforcing their potential suitability for cultivation in Morocco's agro-climatic conditions. These results are consistent with the observations by Elwahab *et al.* (2025), who noted the high productivity of certain rice varieties under Mediterranean climate conditions, similar to those found in Morocco. These high-yielding varieties offer promising candidates for expanding rice production in the region, addressing both food security and economic needs, improving rice production in Morocco or regions facing climatic or economic challenges that require earlier harvesting (varieties like 'Lagustino' and 'KF190046' are recommended). Both varieties exhibited shorter maturity durations, which could be advantageous in areas with shorter growing seasons or where early market entry is critical. Similar conclusions were drawn by Yun (2022), who demonstrated the importance of early maturing varieties in regions with unpredictable weather patterns and limited water availability. Early maturing varieties also allow farmers to grow multiple crops per year, increasing land productivity.

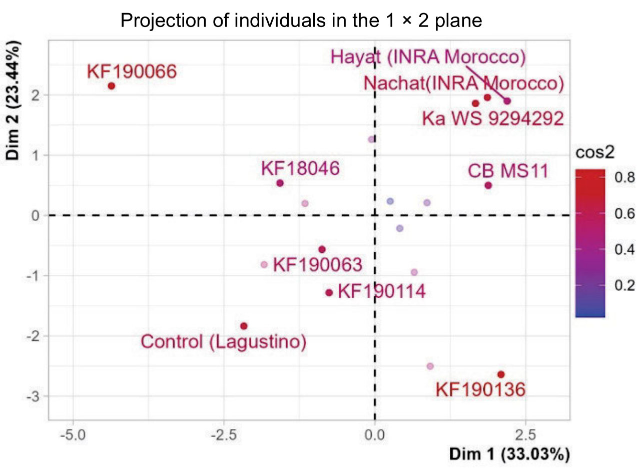

Fig. 4. Individuals graph (principal component analysis) – the individuals with the most input to the construction of the plan are those who have been named; INRA = National Institute of Agricultural Research, Dim = dimension, cos2 = squared cosine; source: own study

The hierarchical cluster analysis (HCA) and principal component analysis (PCA) results reveal distinct patterns of variability among the rice varieties, which are consistent with recent research findings. The traits observed in class 1, such as high plant height, increased seed weight, and longer panicles, align with the findings of Raheem *et al.* (2023), who noted that greater plant height and seed weight are often linked with improved overall morphological traits. These traits are typically associated with better light interception and more robust seed development, which can contribute to higher yield potential. In class 2, rapid maturation and lower panicle production were observed. These traits align with the results reported by Li *et al.* (2024), who suggested that shorter maturation periods and fewer panicles can be beneficial in environments with limited growing seasons or under stress conditions; different rice varieties are affected by climate change in different ways. Developing successful agronomic adaptation plans is essential for the supply of rice worldwide. Nonetheless, there is still a great deal of ambiguity surrounding the best methods or tactics to employ in certain geographical areas. In such cases, quicker maturation allows for early harvesting, reducing the risk of yield loss due to adverse weather conditions, while fewer but well-developed panicles can still maintain sufficient grain yield. The results of Sowmya *et al.* (2023), who found that notable seed yields can occasionally be linked to shorter panicles, are supported by Class 3, which shows high straw and seed output but smaller panicles. This suggests a balance between the size of the panicle and the overall seed yield, since the weight or number of the seeds may counteract the shortening of the panicle.

Furthermore, the clustering results highlight the potential for developing high-yielding rice varieties with improved seed quality and better resistance to biotic and abiotic stress. Recent research has highlighted that genetic diversity is a crucial asset for adapting crops to abiotic constraints such as drought, extreme temperatures, and salinity. For example, Benitez-Alfonso *et al.* (2023) proved that the use of diverse genetic resources can enhance resistance to challenging environmental conditions in major crops, such as rice. Furthermore, research conducted by McNally and Henry (2023) highlighted the importance of leveraging preserved genotypes in international gene banks for the breeding and selection of climate-resilient varieties These conclusions align with the requirements of the Moroccan context, where water pressure and unpredictable seasonal variations have a significant impact on rice production.

Finally, the extended growth periods and higher panicle and tiller counts observed in class 4 align with empirical findings that varieties with longer growth durations tend to produce more panicles (Li *et al.* 2019). They emphasised the importance of longer maturation periods in maximising panicle production and overall yield. This suggests that varieties in this class may be suited for cultivation in environments where longer growing seasons are available, allowing for greater accumulation of biomass and, consequently, higher yield potential. In conclusion, these results highlight the diverse growth and yield characteristics of the rice varieties under study, each offering distinct advantages depending on the environmental and agricultural context. Further research should focus on exploring these relationships in greater depth, especially in terms of optimising breeding strategies and cultivation practices to enhance rice productivity and sustainability.

CONCLUSIONS

The agro-morphological characterisation of 18 cultivated rice varieties in Morocco, analysed through principal component analysis (PCA) and hierarchical cluster analysis (HCA), provided significant insights into their agronomic performance and genetic diversity. The results highlighted key traits such as seed and straw yields, tillering capacity, panicle count, and maturity periods, which are essential for selecting varieties suited to the specific climatic and agricultural conditions of Morocco. The high-yielding varieties, notably 'KF190064' and 'KF190066', demonstrated superior seed and straw yields, making them ideal candidates for improving productivity in Morocco's rice cultivation. Additionally, 'Hayat' (INRA – National Institute of Agricultural Research – Morocco) emerged as another promising cultivar, showing strong performance in both seed and straw yields. These varieties are well-suited for regions where maximising yield is a priority. For areas where early harvests are essential, such as those facing specific climatic or economic constraints, 'Lagustino' and 'KF190046' stand out as the most suitable choices due to their early maturity. These varieties can help optimise production cycles and meet market demands in regions with shorter growing seasons. Furthermore, the study identified varieties with specific traits that could be valuable for future breeding programs. Varieties such as 'Nachat' and 'KF190136', with longer maturity periods or reduced plant heights, offer valuable genetic resources for breeding programs targeting resilience, adaptability, and other essential agronomic characteristics. Overall, the findings provide a comprehensive understanding of the diversity within Moroccan rice varieties and suggest several promising candidates for improving rice production in the region.

SUPPLEMENTARY MATERIAL

Supplementary material to this article can be found online at https://www.jwld.pl/files/Supplementary_material_65_Elwahab.pdf.

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CONFLICT OF INTERESTS

All authors declare that they have no conflict of interests.

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