

Registration and Release of Four Multipurpose Potato Varieties for Commercial Use in Nigeria

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Abstract

Potato yields in Nigeria are among the lowest in the world due to the low availability of high-yielding, disease-resistant, and climate-resilient varieties. Additionally, there is a shortage of varieties that meet the market's processing profile. From 2022 to early 2023, on-station, multi-location, and on-farm trials were conducted by the National Root Crops Research Institute (NRCRI), Umudike, in collaboration with the International Potato Centre (CIP), leading to the recommendation of CIP392797.22 (Unica), CIP393371.157 (Juriya), CIP393371.58 (Babban), and CIP398190.200 (Kyau) to the National Variety Release Committee (NVRC) for registration and release for commercial use in Nigeria. NVRC accepted this recommendation at its June 2023 meeting. With a potential tuber yield of 44–45 tons per hectare, representing a 100% yield advantage over the check varieties, and their better resistance to late blight, bacterial wilt, and viruses, these varieties demonstrate significant potential for enhancing the Nigerian potato industry and meeting the diverse demands of consumers across various market segments. Their superior yield, disease resistance, nutritional composition, and organoleptic properties make them ideal for release as new potato varieties, contributing to the sustainability and growth of the potato sector in Nigeria.

Keywords: Potato, Variety registration, Única, Juriya, Babban, Kyau

Introduction

Potatoes rank fifth, after sugarcane, maize, rice, and wheat, in terms of production volume, as one of the most important food crops worldwide due to their nutritional value, climate resilience, and multipurpose use. Global production of the crop reached 376 million metric tons in 2023, making it the foremost root and tuber crop worldwide (FAOSTAT, 2023). With an estimated 350,000 hectares of production, Nigeria boasts one of the largest potato production areas on the African continent. The temperate climate of Plateau State in the north-central part of Nigeria is ideal for potato production. Approximately 95% of production occurs in nine Local Government Areas of Plateau State, while the remaining 5% is found in the Mambila Highlands of Taraba State and the Obudu Hills of Cross River State (Gildemacher & Belt, 2019). Despite favourable growing conditions, potato yields in Nigeria are the lowest on the continent, at 4-6 tonnes per hectare (NRCRI, 2005). Low yields prevent farmers from realizing the full potential of the potato (up to 40-60t/ha).

Potato producers in Nigeria face several challenges that hinder them from realizing their potential yields. These include limited access to suitable improved varieties, lack of access and availability of quality seed, diseases, including late blight, bacterial wilt, virus, and the use of inappropriate crop production and management practices (CIP, 2021; NAERLS, 2017). Chronic seed insecurity leads producers to reuse seeds of potato varieties that are already infected or have low resistance to pervasive diseases. This contributes to seed degeneration by building up diseases.

Until recently, only six potato varieties, VC804-4, VC785-2, and BR63-18 (registered in 2005), and Marabel, Jelly, and Rhumba (released in 2016), were available to farmers and end-users. Other potato varieties, such as Nicola, Bertita, and Caruso, which are grown and consumed by local farmers, are not registered. These varieties are susceptible to late blight, and farmers have increasingly suffered yield losses in recent years. Moreover, the production of early generation seed from some registered varieties is also restricted by the proprietary rights on those varieties, which prevent any seed producers from multiplying and selling the seed without the consent of the owners. Furthermore, seed importation has been unsustainable due to the complex logistics, lengthy process, and high cost involved, making the seed too expensive for resource-limited farmers in the end. Therefore, the deployment of public (open-access) varieties would be a viable option for variety and seed system development in the country.

To support Nigeria in developing and improving the homegrown seed potato system, the International Potato Centre (CIP), through a German Agency for International Cooperation (GIZ)-funded project, sent eight advanced genotypes from its potato breeding program to Nigeria for release and registration. The genotypes are high-yielding, tolerant to diseases and heat, and most importantly, are public germplasm. In addition, these genotypes also possess good

processing attributes for fries, chips, boiled, cooking, and table. These traits constitute key driving factors in Nigeria's potato processing industry. They have a high potential to sustainably boost production levels of these emerging industries and new markets. Fresh potatoes and their derived products are not only crucial as industrial raw materials but also vital for human nutrition (Nweke 2004). Some of these genotypes have been released as varieties for commercial use in countries such as Peru, Kenya, Uganda, Rwanda, Ethiopia, and Mozambique. The genotypes presented here for release have the potential to replace existing varieties. Ultimately, this novel set of varieties will accelerate the attainment of the Federal Government of Nigeria's potato development initiatives.

To register and release these genotypes for commercial use in Nigeria, the National Root Crops Research Institute (NRCRI) Potato Research Sub-Station in Kuru, Plateau State, assessed them through on-station, multilocation, and on-farm trials. The release of these new, improved varieties for food security and commercial use in Nigeria is envisaged to achieve the following outputs: (i) greater accessibility to favored and high-yielding potato varieties can aid in the development and promotion of the seed system; (ii) increased choice of improved potato varieties that are tolerant to biotic and abiotic factors, thus contributing to improved food security in the face of climate change; and (iii) more options for better potato varieties to meet the needs of different market sectors and consumer demands.

Materials and Methods

Potato genotypes

Eight advanced potato genotypes, namely CIP398190.200, CIP393371.58, CIP398797.22, CIP394611.112, CIP393371.157, CIP398208.29, CIP39095.65, and CIP381381.13, were used for on-station and multilocation trials. The advanced clones were obtained from the International Potato Centre (CIP) in Lima, introduced as tissue-culture in vitro plantlets, and multiplied through rooted apical cuttings (RAC) at the Potato Research Sub-Station, National Root Crops Research Institute in Kuru, Plateau State, Nigeria. For on-farm trials, genotypes CIP398190.200, CIP393371.58, CIP398797.22, CIP393371.157, CIP398208.29, and CIP381381.13 were evaluated alongside Marabel and Nicola as national and local checks. Pre-sprouted and uniform-sized seed potato tubers produced from RACs were used for on-station multi-location and on-farm trials.

On-station Trial

On-station trials were conducted at Kuru during the rainy season of 2022 and the dry season of 2022-2023, respectively. The plot size was 3 x 4 m², with rows spaced 75 cm apart. Seed tubers were planted 30 cm apart at a depth of 15 cm in each row, resulting in a population density of 44,444 plants per hectare. The trial was laid out in a Randomized Complete Block Design with 4 replications. Planting and field management followed recommended agronomic practices by Amadi *et al* (2009). Data were collected on growth (% emergence at 4 weeks after planting WAP), canopy size (cm), plant height (cm), number of leaves, number of stems, stem diameter (cm), number of branches; reaction to diseases (late blight, bacterial wilt, virus (PVY, PVX, leafroll) and tuber yield (number and weight of tubers per plant). Disease severity was scored on a five-point scale (where 1= highly resistant, 2= moderately resistant, 3=tolerant, 4=susceptible and 5=highly susceptible). Late blight, bacterial wilt, and virus (PVX, PVY, leaf roll) were present only during the 2022 rainy cropping season; therefore, only the 2022 rainy cropping season data was collected.

Multi-location Trial

Due to the limited agro-ecological niche for potato production in Nigeria (10-16°C night temperature is required for potato tuberization), multi-location trials were established in eight locations in three states in the rainy season of 2022 and 2022/2023 dry seasons (Table 1). Eight advanced potato genotypes were evaluated with Marabel and Nicola as checks. Planting was carried out in May 2022 (2022 cropping season) and December 2022 (2022/2023 dry season under irrigation). Design, agronomic management practices, and data collection followed the on-station trial protocols.

Table 1. List of State, LGA, village name with GPS coordinates and altitude for 2022 and 2023 cropping seasons' on-station and multi-location trials

SN	Year	Trial name	State	LGA Name	Village	GPS coordinate	Altitude (masl)
1	2022	On-station	Plateau	Jos South	Kuru	9°44'22"N 8°48'24"E	1401
2	2022	Multilocation	Plateau	Barkinladi	Rahol kassa	9°39'55"N 8°56'56"E	1313
3	2022	Multilocation	Plateau	Bokkos	Kunet 1	9°18'08"N 8°59'24"E	1325
4	2022	Multilocation	Plateau	Bokkos	Kunet 2	9°18'24"N 8°59'35"E	1310
5	2022	Multilocation	Plateau	Mangu	Hale	6°41'50"N 11°21'21"E	1320
6	2022	Multilocation	Plateau	Pankshin	Fier	9°25'11"N 9°24'15"E	1207
7	2022	Multilocation	Taraba	Sardauna	Nguroje	7°05'11"N 11°02'22"E	1531
8	2022	Multilocation	Taraba	Sardauna	Gembu	6°43'21"N 11°15'01"E	1544
9	2022	Multilocation	Cross river	Obudu	Ranch	6°23'55"N 9°22'11"E	1600
10	2023	On-station	Plateau	Jos South	Kuru	9°44'22"N 8°48'27"E	1245
11	2023	Multilocation	Plateau	Barkinladi	Rahol Kassa	9°39'35"N 8°56'46"E	1206
12	2023	Multilocation	Plateau	Barkinladi	Bisichi	9°42'47"N 8°54'43"E	1226
13	2023	Multilocation	Plateau	Bokkos	Kunet 1	9°18'28"N 9°02'47"E	1326
14	2023	Multilocation	Plateau	Bokkos	Kunet 2	9°17'58"N 8°59'06"E	1315
15	2023	Multilocation	Plateau	Mangu	Hale	9°32'26"N 9°04'38"E	1156
16	2023	Multilocation	Plateau	Pankshin	Fier	9°23'49"N 9°25'01"E	1355
17	2023	Multilocation	Taraba	Sardauna	Gembu	9°42'44"N 11°15'47"E	1523
18	2023	Multilocation	Cross river	Obudu	Ranch	6°22'58"N 9°22'50"E	1596

On-farm Trial

Following multilocation testing across eight locations, six genotypes, namely CIP398190.200, CIP393371.58, CIP398797.22, CIP393371.157, CIP398208.29, and CIP381381.13, were selected for on-farm testing and evaluations in fifteen locations across three states (Table 2). Due to the limited number of seeds, unbalanced on-farm trials were designed in which individual host farmers evaluated three test genotypes and two check varieties (Marabel and Nicola) (Table 3). On-farm trials were planted in December 2022 under irrigation and were harvested in March 2023

Table 2. List of States, LGAs, villages where on-farm trials were conducted during the 2022/2023 dry season, with GPS coordinates and altitude

SN	Trail	State	LGA Name	Village	GPS coordinate	Altitude (masl)
1	On-farm	Plateau	Barkinladi	Bisichi	9°42'23"N 8°54'48"E	1244
2	On-farm	Plateau	Barkinladi	Doruwa	9°30'36"N 8°59'57"E	1303
3	On-farm	Plateau	Barkinladi	Rahol Kassa	9°34'48"N 8°54'56"E	1271

4	On-farm	Plateau	Bokkos	Kunet1	9°20'9"N 8°57'56"E	1369
5	On-farm	Plateau	Bokkos	Kunet2	9°20'9"N 8°57'56"E	1368
6	On-farm	Plateau	Bokkos	Kunet3	9°20'10"N 8°57'55"E	1364
7	On-farm	Plateau	Jos South	Kavitex	9°41'9"N 8°51'6"E	1298
8	On-farm	Plateau	Jos South	NIPSS	9°45'0"N 8°48'5"E	1250
9	On-farm	Plateau	Jos South	Zawan	9°46'19"N 8°52'5"E	1289
10	On-farm	Plateau	Mangu	Hale	9°32'14"N 9°04'25"E	1158
11	On-farm	Plateau	Pankshin	Fier	9°19'10"N 9°26'30"E	1313
12	On-farm	Taraba	Sardauna	Gembu	6°43'11"N 11°14'47"E	1538
13	On-farm	Taraba	Sardauna	Nguroje	7°09'16"N 11°05'15"E	1449
14	On-farm	Cross river	Obudu	Newmarket	6°22'55"N 9°23'19"E	1590
15	On-farm	Cross river	Obudu	Ranch	6°23'12"N 9°22'32"E	1609

Proximate composition and Organoleptic Evaluation

Tubers of the six potato genotypes, CIP398190.200, CIP398208.29, CIP393371.157, CIP393371.58, CIP381381.13, CIP 392797.22 and the two check varieties: Marabel and Nicola from the 2022/2023 dry season, were analyzed for proximate composition and organoleptic properties at the Post-Harvest/Product Development Processing Laboratory, NRCRI, Umudike, Nigeria. Proximate composition (moisture, crude protein, crude fat, crude fiber, and ash contents) analyses of tuber samples were performed following the standard method of AOAC (1990). The starch content was determined using the acid hydrolysis method, as described by Ezeigbo *et al.* (2015). The vitamin content of the tubers was determined by the iodine titration method, as described by Ikewuchi and Ikewuchi (2011). Tubers from each genotype were processed by cutting, peeling, and washing potato tubers into 1-1.5 cm slices (chips or French fries) and 1-1.5 mm slices (crisps). The slices were washed in cold tap water to remove surface starch and dried on a clean towel. Frying of crisps and chips was carried out in a domestic deep-fat fryer containing 3 litres of vegetable oil at a constant temperature of 170°C. The samples, after turning brown and dry, were removed from the oil and drained for 30 seconds. Acceptability of the cooked potato tubers, crisps, and chips was determined by a sensory evaluation method, by a panel consisting of 15 regular consumers of potatoes to assess the degree of likeness on a nine-point hedonic scale, where 1= dislike extremely; 5= neither like nor dislike; 9= like extremely.

Table 3. Distribution of six test genotypes and two control checks across 15 on-farm trials during the 2023 cropping season

Location	CIP381381.1 3	CIP393371.157	CIP393371.58	CIP398190.200	CIP398208.29	CIP398797.22	Marabel	Nicola	Total Genotypes ¹
Bisichi		1			1	1	1	1	5
Doruwa	1		1	1			1	1	5
Fier	1				1	1	1	1	5
Gembu	1			1	1		1	1	5
Hale		1	1	1			1	1	5
Kavitex	1	1				1	1	1	5
Kunet1		1		1	1		1	1	5
Kunet2	1			1		1	1	1	5
Kunet3			1	1	1		1	1	5
Newmarket		1			1	1	1	1	5
Nguroje	1		1		1		1	1	5
NIPSS		1		1	1		1	1	5
Rahol Kassa			1	1		1	1	1	5
Ranch	1		1		1		1	1	5
Zawan		1	1			1	1	1	5
Grand total²	7	7	7	8	9	7	15	15	75

¹Three test genotypes plus two control checks were planted in an on-farm

²Number of on-farms that received the test genotype

Data Analysis

Single Trials

A linear mixed model was fitted using the lme4 R package (Bates *et al.* 2015) for each trial: $y = \mu + g + r + \varepsilon$, where y_{ij} represents the phenotype data, μ the mean, g_i the fixed effect of genotype i , r_j , the fixed effect of replication, and ε_{ijl} the residual effect. Entry- mean basis heritability was estimated based on the following equation: $H_m^2 = \frac{\sigma_g^2}{\sigma_g^2 + \sigma_e^2/r}$

Where σ_g^2 is the genetic variance; σ_e^2 is the error variance, and r is the number of replications.

Multi-location trial Analysis

The best linear unbiased estimates (BLUEs) using ASREML-R were estimated by the model: $y_{ij} = \mu + g_i + \beta_j + r_{j(l)} + \varepsilon_{ijl}$ where y_{ij} represents the vector of phenotype data, μ represents the overall (grand) mean of the observations, g_i fixed effect of genotype i , β_j represents the random effects of year-location j distributed $\beta_j \sim N(0, \sigma_\beta^2)$, $r_{j(l)}$ represents a random effect of replication nested with location-year with $r_{j(l)} \sim N(0, \sigma_r^2)$, and ε_{ijl} represents the residual $\varepsilon_{ijl} \sim N(0, \sigma_e^2)$.

Analysis of genotype by environment interaction (GxE)

Adaptability and phenotypic stability analyses were performed by the AMMI method as described in Zobel *et al.* (1988) using the following statistical model:

$$Y_{ij} = \mu + g_i + e_j + \sum_{k=1}^n \lambda_k \alpha_{ik} \gamma_{jk} + r_{ij} + \varepsilon_{ij}$$

Where Y_{ij} is the mean response of genotype i in the environment j ; μ is the overall mean; g_i is the fixed effect of genotype g_i ($i = 1, 2, \dots, g$); e_j is the random effect of environment j ($j = 1, 2, \dots, e$); ε_{ij} is the average experimental error; the Genotype x Environment ($G \times E$) interaction is represented by the factors; λ_k is a unique value of the k^{th} interaction principal component analysis (IPCA), ($k = 1, 2, \dots, p$, where p is the maximum number of estimable main components), α_{ik} is a singular value for the i^{th} genotype in the k^{th} IPCA, γ_{jk} is a unique value of the j^{th} environment in the k^{th} IPCA; r_{ij} is the error for the $G \times E$ interaction or AMMI residue (noise present in the data); and k is the characteristic non-zero roots, $k = [1, 2, \dots, \min(G - 1, E - 1)]$.

On-farm analysis

For the on-farm data, the best linear unbiased estimates (BLUEs) using the lme4 R package were estimated by following the model: $y_{ij} = \mu + g_i + r_j + \varepsilon_{ijl}$, where y_{ij} represents the phenotype data, μ is the overall mean, g_i is the fixed effect of genotype i , r_j is a fixed effect of replication (locations were considered as replication), and ε_{ijl} is the residual.

Results and Discussion

On-station and multi-location trials

Yield and agronomic components

The means of total yield (t/ha) across the locations are presented in Table 4 (rainy cropping season 2022) and Table 5 (dry cropping season 2022/2023). During the rainy season, genotype CIP398190.200 produced the highest average yield at 26.1 t/ha, followed by CIP393371.58 and CIP393371.157 with 25.5 t/ha and 24.6 t/ha, respectively. The two local checks, Nicola and Marabel, each produced less than 10 t/ha across all the sites. Among the sites, the highest average yields were obtained in Fier at 25.2 t/ha, while the lowest yield was recorded at the Obudu Ranch site, with an average yield of 7.3 t/ha. All other sites produced an average yield of over 15 t/ha. In general, all eight genotypes under evaluation produced yields that were more than 10 t/ha higher than those of the local checks during the rainy season. Higher yields were obtained during the dry season than in the rainy season. This is typical of Nigeria, where climatic conditions are unfavorable to disease development during the dry season compared to the rainy season (Figures 1 and 2).

Table 4. Total yield (t/ha) for ten potato genotypes evaluated under multi-location trials in the 2022 cropping season

¹Heatmap for the total yield mean between genotypes across locations

Genotypes	Locations ¹									Genotype Mean	Above best check ²
	Fier	Gembu	Hale	Kunet1	Kunet2	Kuru ³	Nguroje	Rahol kassa	Ranch		
CIP398190.200	31.92	23.52	30.74	27.98	29.98	34.05	20.31	27.33	8.58	26.05	17.5
CIP393371.58	31.13	17.11	30.86	29.12	31.12	32.89	20.58	26.84	9.66	25.48	17.0
CIP393371.157	30.05	24.57	28.46	27.26	29.26	25.65	21.91	26.19	8.38	24.64	16.1
CIP392797.22	29.61	18.82	27.87	24.62	26.62	29.1	12.13	24.72	9.06	22.51	14.0
CIP398208.29	24.21	22.95	25.25	23.74	25.74	25.26	22.3	23.88	8.25	22.4	13.9
CIP398098.65	30.27	21.94	27.41	23.96	25.96	25.53	11.26	25.72	6.78	22.09	13.6
CIP394611.112	24.63	18.67	26.1	22.79	24.79	25.85	13.6	21.34	9.44	20.8	12.3
CIP381381.13	24.71	16.93	22.83	21.7	23.7	22.1	15.61	20.81	7.29	19.52	11.0
Nicola	12.57	9.49	7.54	8.32	10.32	7.75	7.38	10.51	2.81	8.52	0.0
Marabel	12.62	8.81	8.49	8.05	10.05	8.88	5.49	6.93	2.62	7.99	-0.5
Location means	25.17	18.28	23.56	21.76	23.76	23.71	15.06	21.43	7.29		

²This value is obtained by subtracting the mean yield of the best check from the test genotype's

³On-station trial result is presented here

Table 5. Adjusted means of total yield (t/ha) for ten potato genotypes evaluated under multi-location trials in the 2023 cropping season

Genotypes	Locations ¹									Genotype Mean	Above best check ²
	Bisichi	Fier	Gembu	Hale	Kunet1	Kunet2	Kuru ³	Rahol kassa	Ranch		
CIP393371.157	42.39	35.92	40.54	41.77	41.46	42.55	44.34	41.92	34.22	40.57	23.34
CIP392797.22	43.77	35.36	42.24	39.53	40.51	42.79	44.27	42.35	32.8	40.4	23.17
CIP398190.200	39.44	40.86	42.2	41.28	39.31	38.34	44.23	40.65	32.4	39.86	22.63
CIP393371.58	33.69	33.42	43.5	37.67	39.85	42.41	45.28	44.92	35.66	39.6	22.37
CIP394611.112	36.77	32.91	39.36	40.15	35.94	43.38	43.50	41.02	33.18	38.47	21.24
CIP398098.65	39.71	28.99	39.15	34.93	37.49	43.90	42.8	42.85	34.64	38.28	21.05
CIP398208.29	37.52	31.02	38.74	41.71	38.97	38.63	43.20	41.56	30.47	37.98	20.75
CIP381381.13	38.48	30.1	38.6	35.49	38.03	35.07	41.75	42.85	35.23	37.29	20.06
Marabel	17.94	17.34	16.25	13.52	18.2	14.83	22.76	17.33	16.92	17.23	0
Nicola	11.87	12.82	8.52	9.26	11.47	12.1	13.54	13.41	10.98	11.55	-5.68
Location mean	34.16	29.87	34.91	33.53	34.12	35.4	38.57	36.89	29.65	34.12	

¹Heatmap for the total yield mean between genotypes across locations

²This value is obtained by subtracting the mean yield of the best check from the test genotype's

³On-station trial result is presented here

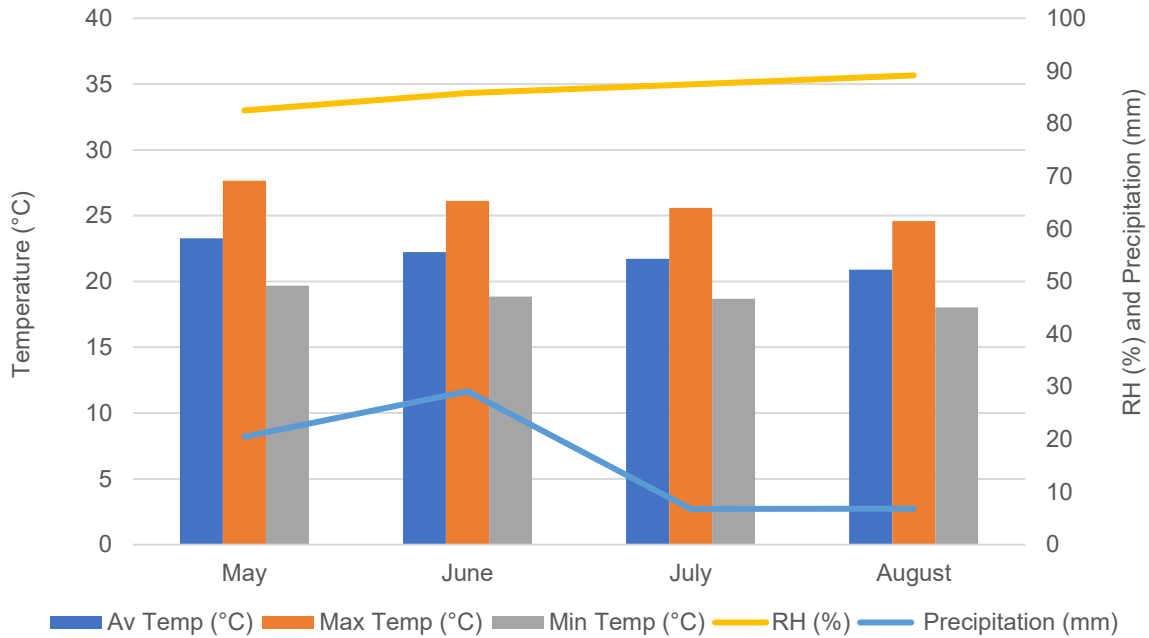


Figure 1. Average monthly weather (Average temperature (°C), Maximum temperature (°C), Minimum temperature (°C), relative humidity (%), and precipitation (mm)) data in Plateau State during the 2022 cropping season (May-August 2022)

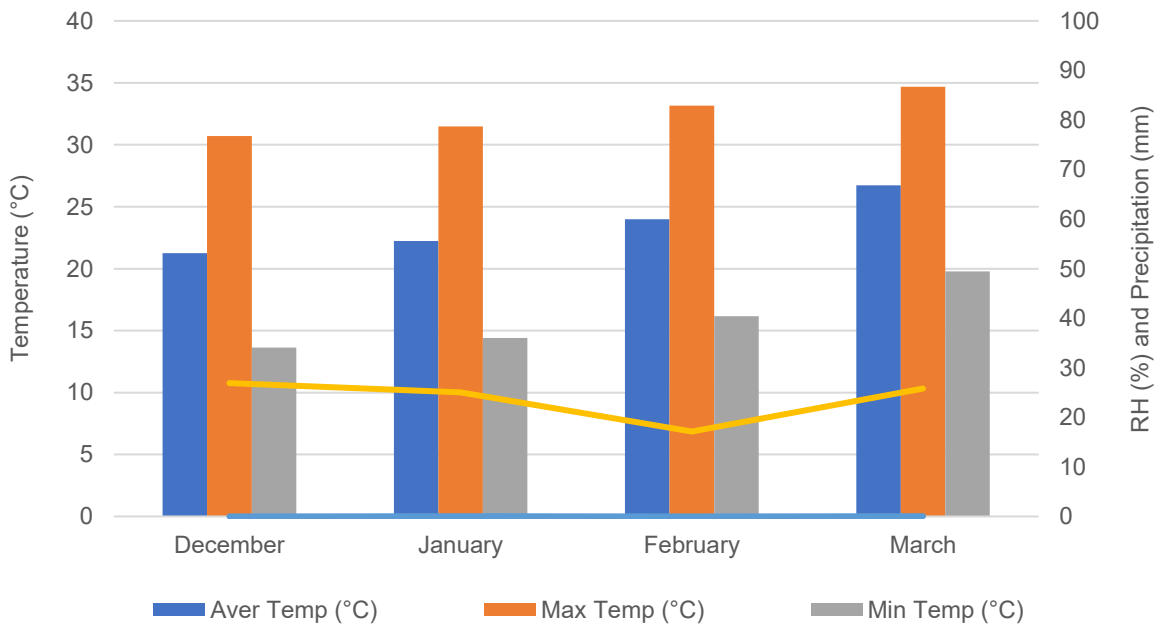


Figure 2. Average monthly weather (Average temperature (°C), Maximum temperature (°C), Minimum temperature (°C), relative humidity (%), and precipitation (mm)) data in Plateau State during the 2022-2023 cropping season (December 2022-March 2023)

The AMMI2 biplot was generated to visualize the first two principal components (IPCA1 and IPCA2) of the G x E interaction for the Total tuber yield per unit area (TTYNA) variable in the 2022 rainy season and 2022/2023 dry season. Figures 3 and 4 present the results for the 2022 rainy season and 2022/2023 dry season. The results obtained indicate that all the tested genotypes expressed some level of stability across the different environments for both seasons. Genotypes closer to each other in the biplot exhibited similar performance patterns, while locations in proximity indicated comparable environmental conditions. This analysis provided insights into the variation and interaction between the genotypes and environments, allowing for a better understanding of the performance of the potato genotypes across different locations. Thus, both yield and IPCA1 and IPCA2 scores should be considered simultaneously to utilize the beneficial effect of GEI and to make more accurate recommendations of the genotypes.

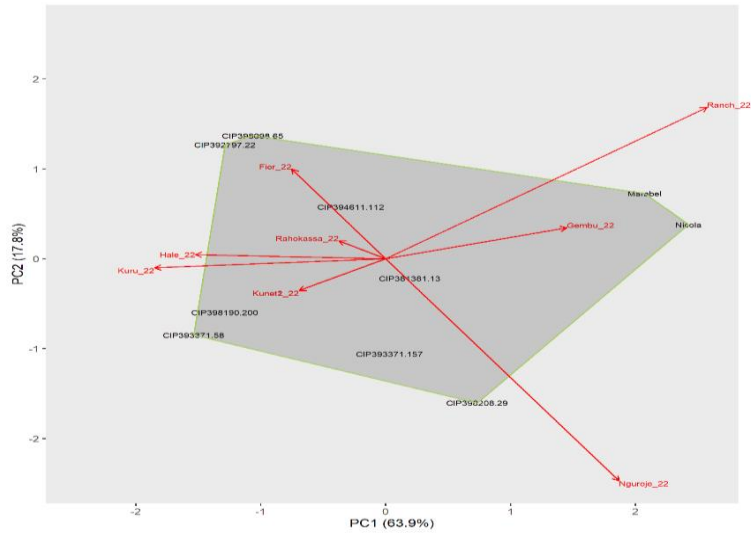


Figure 3. AMMI2 biplot showing the first two variables axes of interaction (IPCA1 and IPCA2) for the Total Tuber Yield per unit area (TTYNA) variable of 10 potato genotypes evaluated in eight locations in Nigeria, 2022.

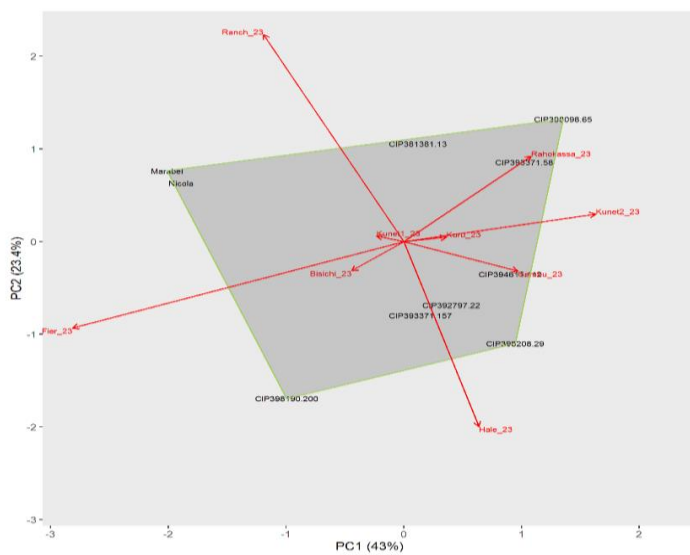


Figure 4. AMMI2 biplot showing the first two variables axes of interaction (IPCA1 and IPCA2) for the Total tuber yield per unit area (TYNA) variable of 10 potato genotypes evaluated in nine locations in Nigeria, 2022

The total tuber yield (t/ha), total number of tubers per plant, number of marketable tubers per plant, and marketable tuber yield (t/ha), plant height (cm) and ranking of ten potato genotypes evaluated under multi-location trials in 2022 rainy cropping season and 2022/2023 dry cropping season are presented in Table 6. CIP398208.29 produced the highest average number of marketable tubers per plant (NMTPL) (11.4), followed by CIP381381.13, while Marabel and Nicola gave the lowest at 4.3 and 2.9, respectively. On the total number of tubers per plant (TNTPL), the highest number of tubers was still produced by CIP398208.29, followed by CIP381381.13, while Nicola gave the lowest number (7.4). However, this high number of tubers did not result in higher yields, as CIP398190.200 produced the highest average marketable and total yield, followed by CIP393371.157 and CIP393371.58, respectively, which did not have the highest tuber number. Marabel and Nicola were ranked second last and last, respectively, in both marketable yield and total yield.

Table 6. Means of total tuber yield (t/ha), total number of tubers per plant, number of marketable tubers per plant, and marketable tuber yield (t/ha), plant height (cm) and ranking of ten potato genotypes evaluated under multi-location trials in 2022 rainy cropping season and 2022/2023 dry cropping season

Genotype	Yield components partitioning				Plant height (cm)	Rank ²
	nmtpl	tntpl	mtyna	ttyna*		
CIP398190.200	8.4	11.6	28.4	33.0	81.1	1
CIP393371.157	8.4	11.8	28.0	32.6	84.7	2
CIP393371.58	8.0	11.4	27.9	32.5	96.8	3
CIP392797.22	6.5	9.6	26.9	31.5	80.8	4
CIP398208.29	11.4	14.7	25.6	30.2	82.0	5
CIP398098.65	8.6	12.1	25.8	30.2	83.5	6
CIP394611.112	7.2	10.4	24.8	29.6	83.1	7
CIP381381.13	9.9	13.6	23.9	28.4	97.2	8
Marabel	4.3	10.0	8.1	12.6	57.6	9
Nicola	2.9	7.4	5.4	10.0	50.7	10

¹NMTPL: number of marketable tubers per plant, TNTPL: total number of tubers per plant, MTYNA: marketable tuber yield (t/ha), TTYNA: total tuber yield (t/ha)

⁴Ranking of the candidate varieties based on the TTYNA (t/ha)

Reactions of the genotypes to common diseases

Evaluated genotypes exhibited different levels of resistance to the major potato diseases, including late blight (LB), bacterial wilt (BW), and common potato viruses (PVY, PVX, and PLRV) as indicated in Table 7. The genotypes, CIP398190.200, CIP398371.157, and CIP398371.58 exhibited higher resistance to LB, CIP381381.13 was moderately resistant, while CIP392797.22, CIP398098.65, and CIP394611.112 were tolerant. The two local checks were highly susceptible to LB. No genotype showed high resistance against BW. However, CIP398371.157, CIP398371.58, and CIP392797.22 showed moderate resistance to BW, while five genotypes showed some level of tolerance against BW compared to the two highly susceptible checks. Genotypes CIP398371.58 and CIP381381.13 were highly resistant to PVY. CIP398371.58 and CIP392797.22 were highly resistant to PVX, while CIP398190.200, CIP398371.58, CIP392797.22, and CIP381381.13 showed high resistance to PLRV. The two checks were either susceptible or highly susceptible to the three classes of viruses. In general, the genotype under evaluation exhibited higher levels of resistance to LB and viruses compared to the checks.

Table 7. Means of late blight severity score, bacterial wilt severity score, and virus (PVY, PVX, leafroll) severity score of ten potato genotypes evaluated in multi-location trials in the 2022 rainy cropping season

Genotype	Late Blight ¹	Bacterial Wilt ^{1,2}	Virus ¹		
			PVY	PVX	Leaf roll
CIP398190.200	1	3	2	2	1
CIP393371.157	1	2	2	1	2
CIP393371.58	1	2	1	1	1
CIP392797.22	3	2	2	1	1
CIP398208.29	3	3	3	3	3
CIP398098.65	3	3	3	3	3
CIP394611.112	3	3	2	2	3
CIP381381.13	2	3	1	2	1
Marabel	5	5	4	4	4
Nicola	5	5	5	5	5

¹Disease severity was scored on a five-point scale (where 1= highly resistant, 2= moderately resistant, 3=tolerant, 4=susceptible and 5=highly susceptible)

On-farm trials

Yield performance across farmers' fields

Results recorded from on-farm evaluations indicated that the tested genotypes outperformed the national check across sites for yield traits (Table 8). Genotype CIP393371.58 ranked 1st with 39.48 t/ha, followed by CIP392797.22 (39.22 t/ha), CIP398190.200 (38.96 t/ha), CIP393371.157 (38.74 t/ha), CIP381381.13 (37.74 t/ha), and CIP398208.29 (35.24 t/ha). Although CIP398208.29 ranked lowest among the test genotypes, its yield was higher than the best check (8.02 t/ha).

Table 8. Means from on-farm trials for number of marketable tubers per plant, total number of tubers per plant, marketable tuber yield (t/ha), and total tuber yield (t/ha)

Genotypes	Yield components partitioning				Above best check	Rank ²
	NMTPL	TNTPL	MTYNA	TTYNA		
CIP393371.58	12.02	14.91	36.55	39.48	22.34	1
CIP398797.22	10.61	13.42	36.75	39.22	22.07	2
CIP398190.200	12.98	15.56	34.81	38.96	21.81	3
CIP393371.157	12.91	16.20	36.26	38.74	21.59	4
CIP381381.13	12.85	15.40	35.89	37.74	20.60	5
CIP398208.29	13.27	16.07	31.82	35.24	18.09	6
Marabel	7.21	10.55	11.80	17.15	0.00	7
Nicola	3.96	7.29	4.80	8.02	-9.13	8

¹NMTPL: number of marketable tubers per plant, TNTPL: total number of tubers per plant, MTYNA: marketable tuber yield (t/ha), TTYNA: total tuber yield (t/ha)

²Ranking of the candidate varieties based on the TTYNA (t/ha)

Farmers' assessment of the tested genotypes

Farmers assessed the tested genotypes at harvest using a ranking scale of 1-5, where 1 is most preferred and 5 is least preferred. The acceptability of yield traits of the tested genotypes based on farmers' assessment, across locations, is presented in Table 9. Overall, farmers indicated that test genotypes were preferred over local checks across different locations. This suggests the potential acceptability and adoption of our test genotypes as substitutes or replacements for local varieties.

Table 9. Frequency of ranking of tested genotypes and local checks based on yield traits (total yield, marketable yield, and tuber numbers per plant) at harvest by host farmers.

Genotypes	Number of locations	Rank ¹				
		1 st	2 nd	3 rd	4 th	5 th
CIP381381.13	7	3	2	2		
CIP393371.157	7	4	2	1		
CIP393371.58	7	5	1	1		
CIP398190.200	8	5	2	1		
CIP398208.29	9	4	3	2		
CIP398797.22	7	5	2			
Marabel	15				13	2
Nicola	15				2	13

¹Raking scale of 1-5 where 1st is most preferred, and 5th is least preferred

Proximate composition and organoleptic properties of genotypes evaluated

Proximate composition

Data on the proximate composition of the genotypes evaluated are presented in Table 10. The local check, Nicola, had the highest moisture content of 81.3%, followed by CIP392797.22 and Marabel at 79.1% and 78.9%, respectively. Genotype CIP398371.157 had the lowest moisture content at 69.6%. All the evaluated genotypes had higher ash, fibre, and protein content compared to the checks. Genotype CIP398371.157 had the highest starch content at 35%. Other genotypes had higher than 20% starch, except the two checks, which had less. Genotypes CIP381381.13, CIP398190.200, and Nicola had Vitamin C content greater than 78 mg/100g, while for other genotypes, Vitamin C content ranged from 51-53 mg/100g. All the evaluated genotypes had higher dry matter content than the local checks, except CIP392797.22, with CIP398371.157 having the highest dry matter content of over 30%. The results of the proximate analysis indicate that the test genotypes possess the required traits to fit into the different potato market segments. These values provide insights into the nutritional composition and potential uses of the potato genotypes.

Table 10. Proximate composition (moisture (%), ash (%), fiber (%), protein (%), fat (%), CHO (%), dry matter (%), vitamin C (mg/100g), and starch content (%) of eight genotypes of 2023 cropping season

Genotype	Moisture (%)	Ash (%)	Fiber (%)	Protein (%)	Fat (%)	CHO (%)	Dry matter (%)	Vitamin C (mg/100g)	Starch content (%)
CIP381381.13	72.5	1.3	0.9	5.7	2.3	17.2	27.5	78.4	24.2
CIP392797.22	79.1	1.6	0.8	4.4	3.2	11.0	20.9	52.3	21.5
CIP393371.157	69.6	1.0	0.9	4.0	1.9	22.5	30.4	52.4	35.9
CIP393371.58	72.1	1.1	0.9	5.7	1.9	18.4	27.9	52.2	26.1
CIP398190.200	70.6	1.4	0.8	6.0	2.6	18.7	29.5	78.1	25.3
CIP398208.29	74.6	1.7	0.9	3.9	1.7	17.3	25.5	52.6	24.6
Marabel	78.9	0.5	0.6	1.9	2.7	15.5	21.1	51.4	16.0
Nicola	81.3	0.5	0.6	2.4	1.9	13.3	18.7	78.2	17.8

Organoleptic properties

Results on organoleptic properties of tubers processed into Boiled tubers, French fries, and Crisps are presented in Table 11. For table use, all genotypes did not differ significantly. The average scores for colour, taste, mealiness, crookedness, and overall acceptability were similar for all except for Nicola, which had slightly lower scores on taste, mealiness, and crookedness, indicating that the genotypes were equally acceptable to the evaluating panel. Concerning cooking time for table consumption, CIP381381.13 took the longest time (33 minutes), while Nicola took the shortest (21 minutes). Other genotypes ranged between 24-31 minutes of cooking time. On French fries, there was similar acceptability of the genotypes on colour, taste, crunchiness, mouth feel, and general acceptability. Cooking time for French fries, however, differed among the genotypes. CIP398208.29 took the shortest time (7 minutes), followed by Marabel and CIP381381.13, which took a similar time of 9 minutes. CIP392797.22 and CIP398371.157 took the longest time (13 minutes). For crisps, similar acceptability scores were observed on colour, taste, crunchiness, and

general acceptability. Three genotypes, CIP398371.58, CIP398190.200, and CIP398208.29, had a lower score of 6 on Mouth feel. The cooking time for crisp was generally low among the genotypes, ranging from 4 to 6 minutes

Table 11. Organoleptic properties of ten genotypes from the 2023 cropping season

¹Degree of likeness was scored on a nine-point hedonic scale, where 1= dislike extremely; 5= neither like nor dislike; 9= like extremel

Conclusion

The National Root Crops Research Institute (NRCRI), Umudike, Nigeria, in collaboration with the Center for Potato Improvement (CIP), Lima, Peru, nominated six candidate varieties, namely CIP381381.13, CIP392797.22,

Genotypes	Table					French fries					Crisps							
	Colour ¹	Taste ¹	Mealiness ¹	Cookedness ¹	Acceptability ¹	time Cooking (minutes)	Colour ¹	Taste ¹	Crunchiness ¹	Mouth feel ¹	Acceptability ¹	time Cooking (minutes)	Colour ¹	Taste ¹	Crunchiness ¹	Mouth feel ¹	Acceptability ¹	time Cooking (minutes)
CIP381381.13	7	7	7	7	7	33	8	7	6	8	8	9	8	8	8	7	8	4
CIP392797.22	9	8	8	7	8	25	8	8	7	7	8	13	8	7	7	7	8	5
CIP393371.157	8	7	8	8	7	24	8	7	7	7	7	10	8	8	8	7	8	4
CIP393371.58	8	7	8	7	7	27	7	7	8	7	8	13	8	8	7	6	7	6
CIP398190.200	8	8	8	8	8	27	8	7	7	7	7	10	7	7	7	6	7	5
CIP398208.29	7	7	7	7	8	25	8	8	7	7	7	7	7	7	7	6	6	4
Marabel	8	8	7	8	8	31	8	7	7	7	7	9	7	8	7	8	8	4
Nicola	7	6	6	6	7	21	7	7	7	6	7	11	8	7	7	7	8	5

CIP393371.157, CIP393371.58, CIP398190.200, and CIP398208.29, to the National Variety Release Committee for registration and release for commercial use in Nigeria. Four of these - CIP392797.22, CIP393371.157, CIP393371.58, and CIP398190.200 were released officially as Unica, Juriya, Babban, and Kyau, respectively. These varieties surpassed the yield of checks by more than twice across all trial locations. These yields were stable across all the sites and seasons. The varieties also showed relatively higher levels of resistance and/or tolerance to the most common potato diseases in Nigeria compared with the local checks. The proximate composition of these candidate varieties indicated their superiority in nutritional and quality traits compared with the checks. The acceptability of these candidate varieties for different end uses was high. The distinctive characteristics of the released varieties are shown in Table 12, along with pictorials in Figures 5-8. The availability of these high-yielding, farmer- and consumer-preferred potato varieties will enhance the development of a sustainable seed production and marketing system and expand the potato value chain in Nigeria.

Table 12. Distinguishing characteristics of released potato varieties

Traits	CIP392797.22	CIP393371.157	CIP393371.58	CIP398190.200
	Proposed name: Unica	Proposed name: Juriya	Proposed name: Babban	Proposed name: Kyau
Yield (t/ha)	44.27	44.34	45.28	44.23
Tuber number/plant	12	18	17	17
Dry matter (%)	20.9	30.4	27.9	29.5
Starch content (%)	21.5	35.9	26.1	25.3
Flower color	Pink	Pink	White	Pink
Tuber skin color	Red	White cream	White cream	White cream
Tuber flesh color	Cream	Cream	Cream	Cream
Tuber shape	Oblong	Oblong	Oblong	Oblong
Eye depth	Shallow	Shallow	Shallow	Shallow
Eye color	Dark pink	Pinkish	Pink	Pink
Dormancy (days)	75	110	110	110
Maturity (days)	80-90	120	120	120
Plant description	Medium tall plant with strong semi-erect stems and dark green medium sized leaves	Medium tall plant with strong semi erect stems and dark green medium size leaves	Semi- erect tall plant (about 1 meter in height) with strong stems and light green medium-sized leaves	Medium tall plant with strong semi erect stems and dark green medium size leaves
Level disease resistance/ tolerance	Moderately resistant to Late blight, Bacterial wilt highly resistant to Potato Virus X (PVX), Potato Leaf Roll Virus (PLRV)	Tolerant to Late blight, Potato Virus X, extremely tolerant to Potato Virus Y	Resistant to Late blight, PXV, PLRV	Resistant to Late blight, PXV, PLRV
Level heat/ drought tolerance	Extremely tolerant to heat and drought	Moderately tolerant to heat and drought	Moderately tolerant to heat and drought	Tolerant to heat
Target market	Processing (Crips and French fry), Table (boiled, cooking)	Processing (Crips), Flour, Table (boiled, mashed, cooking)	Processing (French fry), Table (boiled, mashed, cooking)	Table (boiled, mashed, cooking)



Figure 5: Foliage, Flower, Tuber shape, Skin, and Flesh colour of CIP398190.200 (KYAU)



Figure 6: Foliage, Flower, Tuber shape, Skin, and Flesh colour of CIP393371.58 (BABBAN)



Figure 7: Foliage, Flower, Tuber shape, Skin, and Flesh colour of CIP393371.157 (JURIYA)



Figure 8: Foliage, Flower, Tuber shape, Skin, and Flesh colour of CIP398797.22 (UNICA)

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