South African Journal of Botany 185 (2025) 315–330

Contents lists available at ScienceDirect

South African Journal of Botany

journal homepage: www.elsevier.com/locate/sajb

Agro-morphological diversity and breeding potential of Bambara groundnut (*Vigna subterranea* L. Verdc): Insights from recombinant inbred lines evaluation

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ARTICLE INFO

Edited by Dr. S.O Amoo

Keywords:
Genetic diversity
Multivariate analysis
Shannon-weiner diversity index
Vision for adapted crops and soils (VACS)
Underutilized crops

ABSTRACT

Bambara groundnut (BGN) is a nutritious, multi-stress-tolerant legume with potential to enhance food and nutrition security across Africa, particularly in regions vulnerable to climate change and resource scarcity. Its ability to thrive in harsh environments while providing a rich source of protein and essential nutrients makes it an invaluable crop for sustainable agriculture. Despite its proven resilience and benefits, BGN remains overlooked in mainstream agricultural development and research, leaving its full potential untapped. This study evaluated recombinant inbred lines (RILs) derived from hybridization of four genetically diverse parental lines to identify superior genotypes. This research aims to pinpoint elite lines with potential for enhancing future BGN breeding programs, focusing on key agro-morphological traits. The experiment followed a 90 × 5 augmented design, incorporating 21 check lines. Trait measurements adhered to the descriptors provided by the International Plant Genetic Resources Institute. Data analysis included analysis of variance (ANOVA), Pearson correlation coefficient, Principal Component Analysis (PCA) and diversity indices. Quantitative morphological traits (days to 50 % emergence (DE), days to 50 % flowering (DFF), internode length (IL), plant height (pH), and petiole length (PL)) exhibited significant variability among genotypes ($p < 0.001$). Multivariate analysis indicated that the first three principal components (PCs), each with eigenvalues ≥ 1, accounted for 80 % of the total variance. Key correlations include strong positive relationships between DE and DFF ($r = 0.85$; $p = 0.017$), pH ($r = 0.75$; $p = 0.021$) and PL ($r = 0.75$; $p = 0.027$). Petiole length was positively correlated with DFF ($r = 0.89$; $p = 0.01$) and pH ($r = 0.86$; $p = 0.011$). Grain yield per plot (GY) and grain yield per plant (GYP) varied significantly, which aided classification into four groups, namely: A (high-yielding g), B (moderately high yielding), C (moderate yielding) and D (low yielding). A total of 19 genotypes including; IITA686/LunT-419–324, S19/Ankpa4–339–266, IITA686/LunT-348–271, S19/Ankpa4–50–43, S19/Ankpa4–234–197, PONG-BR, S19/Ankpa4–1–1 and S19/Ankpa4–151–129 were grouped as high-yielding. The significant genotypic differences observed across most quantitative traits confirm the presence of sufficient genetic diversity, highlighting BGN's potential for selection and genetic enhancement.

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https://doi.org/10.1016/j.sajb.2025.07.061
Received 4 February 2025; Received in revised form 2 July 2025; Accepted 31 July 2025
Available online 14 August 2025

Introduction

Bambara groundnut (BGN) (*Vigna subterranea* L. Verdc), a herbaceous annual legume of the Fabaceae family, holds significant promise as a resilient and nutritious crop (Mandizvo and Odindo, 2019). Its precise origin remains debated, though it is generally believed to have emerged in West and Southern Africa (Hepper, 1963; Temegne et al., 2018). Bambara groundnut is a crucial plant-based protein source, particularly for rural populations with limited access to animal protein (Drechsel et al., 2001). Additionally, it serves as animal fodder (Bbebe, 2019), a nutraceutical resource (Udeh et al., 2020), and an important source of income for women in rural areas (Mubaiwa et al., 2016). BGN thrives in poor soils and under drought conditions, providing a sustainable option for marginal environments where other crops often fail (Hillocks et al., 2012; Kunene et al., 2022).

Global interest in BGN has grown in recent years, driven by its potential to contribute to climate-resilient agriculture and food security (Mabhaudhi et al., 2019; Olanrewaju et al., 2021). However, despite its agronomic and economic importance, BGN remains underutilized and neglected, primarily due to historically limited research and development investment. Compared to major staple crops such as maize, rice, and wheat, BGN has received minimal attention in breeding, genomics, and genetic improvement (Halimi et al., 2019; Hillocks et al., 2012).

This landscape is changing; several recent initiatives have been launched to accelerate BGN research and improvement. These include: (i) the Vision for Adapted Crops and Soils (VACS) initiative (Herrick et al., 2024), which promotes breeding and adaptation of resilient crops; (ii) the Kirkhouse Trust (KT), which has supported genomics-assisted breeding and marker development for BGN (Canales Holzeis et al., 2024); and (iii) the BamBREED project, which is driving breeding programmes, genomic resource development, and phenotyping efforts across Africa (Mateva et al., 2023; Mohammed et al., 2023). Furthermore, recent advances in molecular markers, high-throughput phenotyping, and transcriptomics have provided new tools for dissecting the genetic architecture of key traits in BGN (Molosiwa et al., 2015; Uba et al., 2023).

Morphological characterization remains a critical foundation for describing and classifying genetic diversity, especially in crops like BGN, where molecular tools are still being optimized (Dar et al., 2022; Muhammad et al., 2020). Agro-morphological markers offer valuable means for identifying desirable gene combinations, supporting the development of improved cultivars tailored to diverse agro-ecological zones (Gbaguidi et al., 2018; Glaszmann et al., 2010; Uba et al., 2021).

However, breeding BGN presents challenges due to its complex floral biology and pollination constraints. The species exhibits cleistogamy, with flowers self-pollinating before opening (Kafoutchoni et al., 2021), and the short flower lifespan (24–48 h) further limits opportunities for artificial hybridization (Onwubiko et al., 2011; Suwanprasert et al., 2006). In addition, the small, delicate floral structures make emasculation difficult.

Recent breakthroughs, such as Gao's successful artificial hybridization at the University of Nottingham (Gao, 2021), have opened new possibilities for targeted breeding. Developing structured populations and segregating lines enables more rigorous genetic studies and trait improvement (Mohammed et al., 2023; Molosiwa et al., 2015). Similarly, the University of Nottingham's efforts in creating F2 bi-parental populations from diverse origins—including IITA-686 (Tanzania) × Tiga Nicuru (Mali) and S19–3 (Namibia) × DodR (Tanzania)—have provided valuable resources for enhancing genetic gain in BGN (Gao, 2021).

In this context of renewed global interest and expanding research capacity, this study evaluates the agro-morphological diversity of recombinant inbred lines (RILs) derived from four pure BGN lines. The primary objectives are to assess the true breeding lines' performance and identify promising candidates for future breeding programmes. By characterizing this diversity, the study aims to contribute to the genetic improvement and sustainable use of BGN, thereby supporting food security and climate-resilient agriculture in developing regions.

Materials and methods

Study site, planting material and experimental design

The study was conducted at the Ukulinga Research Farm in Pietermaritzburg, South Africa (30° 24′S, 29 °24′E). The area is characterised by hot summers and mild winters, with a mean annual temperature of 18.4 °C and an annual rainfall of 680 mm. A total of 346 F_5 recombinant inbred lines (RILs) and 21 check genotypes, including the four parents (S19, ANKPA 4, IITA686 and Lun T) (Table 1), were evaluated in an augmented randomised complete block design (RCBD) laid out in five blocks. Each block contained 69 unreplicated RILs, while all 21 checks were replicated across all blocks. This resulted in 90 plots per block and 450 plots in total. The design allowed for estimating experimental error based on replicated checks, while test entries remained unreplicated. The RILs were developed from the crosses of four parents at the University of Nottingham in 2018, which were advanced to F3 and sent to the University of KwaZulu-Natal (UKZN) in 2019. The F3 families were advanced using the single-seed descent method from the F3 to the F5 generations.

Trial management

Both chemical and manual weed management were carried out at two-week intervals from planting. Pests and diseases were routinely managed by spraying karate Zeon (lambda-cyhalothrin) pesticide and copper oxychloride fungicides until the plants reached physiological maturity.

Data collection

Eight quantitative (Table 2) and three qualitative (Table 3) traits were observed for agro-morphological characterisation during the different stages of growth and development, based on the BGN descriptors established by the International Plant Genetic Resources Institute (Resources and Agriculture, 2000).

Qualitative morphological traits considered were grouped into (i) growth habit, (ii) terminal leaf shape and (iii) terminal leaf colour traits, and each group was represented by a different character state (Table 3). Each genotype was scored for the most frequent character state.

Data analysis

The frequency distribution and Shannon diversity index were calculated for the qualitative traits. The Shannon index (H') was used to calculate the genetic diversity index of each trait by using the following equation (Shannon, 1948):

$$H' = -\sum_{i=1}^{n} pi \ln pi$$

pi: the proportion (n/N); **N**: number of species found in population N; **ln**: a natural logarithm

Analysis of variance for an augmented block design was carried out

Table 1
Bambara groundnut landraces used as parental lines for developing the RILs used in the study.

Genotype	Geographic coordinates	Location
ANKPA 4	7.24° N, 7.38° E	Ankpa, Nigeria
IITA686	6.10° S, 35.46° E	Tanzania
LUNT	8.29° N, 13.14° W	Lungi, Siera Leone
S19	22.33° S, 17.04° E	Namibia

Table 2
Quantitative traits observed and their brief description and codes.

Quantitative trait(s)	Acronym (s)	Unit (s)	Procedure
Days to emergency	DE	days	The number of days from planting to the appearance of the first leaf on the soil surface.
Days to 50 % flowering	DFF	days	The number of days from emergence to when 50 % of the plants have started flowering.
Internode elongation	IL	cm	The average length of the 4th internode was randomly selected from the five longest stems at ten weeks.
Plant height	pH	cm	The height of the main stalk, from the surface to the tip of the main panicle.
Petiole length	PL	cm	The average length of three leaves at the 4th node of the five healthy plants at 10 weeks.
Canopy width	CW	cm	The average widest length between two opposite points of five plants at 10 weeks.
Grain yield	GY	g	The weight of dried seeds at 12 % moisture per plot
Grain yield per plot	GYP	g	The total weight of dried seeds at 12 % moisture per plant

Table 3
Qualitative traits observed and descriptor codes.

Qualitative trait	Code	Measurement
Growth habit	GH	1-bunch type 2-semi-bunch 3-spreading type
Terminal leaf shape	TLS	1-round 2-oval 3-lanceolate 4-elliptic
Terminal leaf colour	TLC	1-green 2-red 3-purple

using Rstudio software Version 4.1.3. Morphological quantitative traits that indicated a significant variation were subjected to a Principal Component Analysis Procedure (PRINCOMP) by using a correlation matrix to define the trait variation patterns using XLSTAT software (Data Analysis and Statistical Solution for Microsoft Excel, Addinsoft, Paris, France, 2022). PCs with eigenvalues ≥ 1 were selected to define the agronomic and morphological trait variation among the accessions.

Results

Frequency distribution for qualitative traits

The three morphological descriptors determined plant variations among the studied BGN genotypes. Table 4 shows the qualitative traits, their variations, and their frequencies. The results showed that 58.5 % of the studied BGN genotypes have a bunch-type growth habit, 18.8 % have a semi-bunch-type habit, and 22.6 % have a spreading-type habit. Among the BGN genotypes, 32.8 % had round terminal leaflets, 40.1 % had an oval shape, 3.3 % had a lanceolate shape, and 23.7 % had an elliptic shape.

Table 4
Frequency of phenotypic traits studied among 365 genotypes.

Trait(s)	Variables	Frequency (%)
Growth habit	Bunch type	58.5
	Semi-bunch type	18.8
	Spreading type	22.6
Terminal leaflet shape	Round	32.8
	Oval	40.1
	Lanceolate	3.3
	Elliptic	23.7
Terminal leaflet colour	Green	96.7
	Purple	3.3

Shannon-Weiner diversity index

The level of phenotypic variation of qualitative traits was estimated using the Shannon diversity index (H'), ranging from 0.2 to 1.19, with a mean of 0.78, indicating a high diversity (Table 5). The terminal leaf shape showed the highest diversity, while the terminal leaf colour showed the least variation.

Analysis of variance

The analysis of variance showed significant differences among the studied genotypes (checks + inbred lines) ($p < 0.05$) (Table 6). A significant block effect was observed in the days to emergence, the plant height, the grain yield per plant and the plot (1.5 m single row); however, the block effect was not significant $p > 0.05$ in canopy width, days to flowering and internode length. The results showed a significant difference between the checks and the tests for most traits, except for the canopy width.

Days to emergence ranged from 12 to 23 days (Fig. 1). The highest DE were recorded in IITA686/LunT-257–216, IITA686/LunT-341–268 and S19/Ankpa4–130–112 while the least DE were recorded in S19/Ankpa4–232–195, S19/Ankpa4–239–202, S19/Ankpa4–25–21 and S19/Anpa4–109–90 (Table 7). The highest DFF (83 days) were recorded in IITA686/LunT-407–317, IITA686/LunT-421–326, IITA686/LunT-434–337 and S19/Ankpa4–36–31, while the least DFF (47 days) was recorded in IITA686/LunT-280–228 and S19/Ankpa4–239–202.

Internode length (IL) ranged from 0.3 to 5.6 cm. The highest IL (5.6 cm) was recorded in S19/Ankpa4–77–67 and the lowest (0.3 cm) in S19/Ankpa4–89–102. The highest pH (34 cm) was recorded in S19/Ankpa4–36–31, followed by IITA686/LunT-344–269 and IITA686/LunT-356–277 (33 cm). The lowest pH (16 cm) was recorded in IITA686/LunT-280–228 and IITA686/LunT-283–229 (Table 7). Petiole length and canopy width ranged from 5.03 to 26.03 cm and 23 to 63 cm, respectively (Table 7 and Fig. 1).

Grain yield per plot (GY) ranged from 2.60 to 132.60 g plot^{-1}, while grain yield per plant (GYP) ranged from 0.34 to 48.53 g plant^{-1} (Fig. 1). The violin shapes illustrate the data distribution and density, while the black box plots represent the interquartile range (IQR), with white dots marking the median values (Fig. 1). Differences in distributions across traits indicate varying degrees of variability within the BGN population.

Correlation analysis

Red ellipses represent positive correlations, while negative

Table 5
Shannon-Weiner diversity indices of the phenotypic traits of BGN genotypes.

Trait	Shannon-Weiner index (H')
Growth habit	0.96
Terminal leaflet shape	1.19
Terminal leaflet colour	0.201
Average diversity index	0.78

Table 6
Mean squares from the Analysis of Variance of augmented RCBD for eight parameters of Bambara groundnut genotypes.

Source of variation	d.f	CW	DE	DF	IL	pH	PL	GY	GYP
Check	20	$109.77^{n.s}$	44.73**	382.95**	5.99**	37.19**	88.72**	2701.8**	179.19**
Test vs check	1	$17.29^{n.s}$	86.46**	780.68**	4.59**	48.11**	383.01**	9773.59**	691.61**
Test (RILs)	345	$113.6^{n.s}$	10.2**	98.65**	9.24**	10.35**	22.1**	696.66**	$50.5^{n.s}$
Block	4	$26.44^{n.s}$	3.00**	$19.57^{n.s}$	$0.74^{n.s}$	5.99*	$6.26^{n.s}$	7814**	528.73**
Residual (Error)	82	105.25	2.69	18.3	0.46	2.2	5.52	806.75	51.76
Total	449	–	–	–	–	–	–	–	–

CW: canopy width; DE: days to emergence; DF: days to 50 % flowering; IL: internode length; PH: plant height; PL: petiole length; GCV: genotypic coefficient of variation; PCV: phenotypic coefficient of variation; n.s: non-significance $p > 0.05$; **: indicates a significance $p < 0.05$; d.f: degrees of freedom

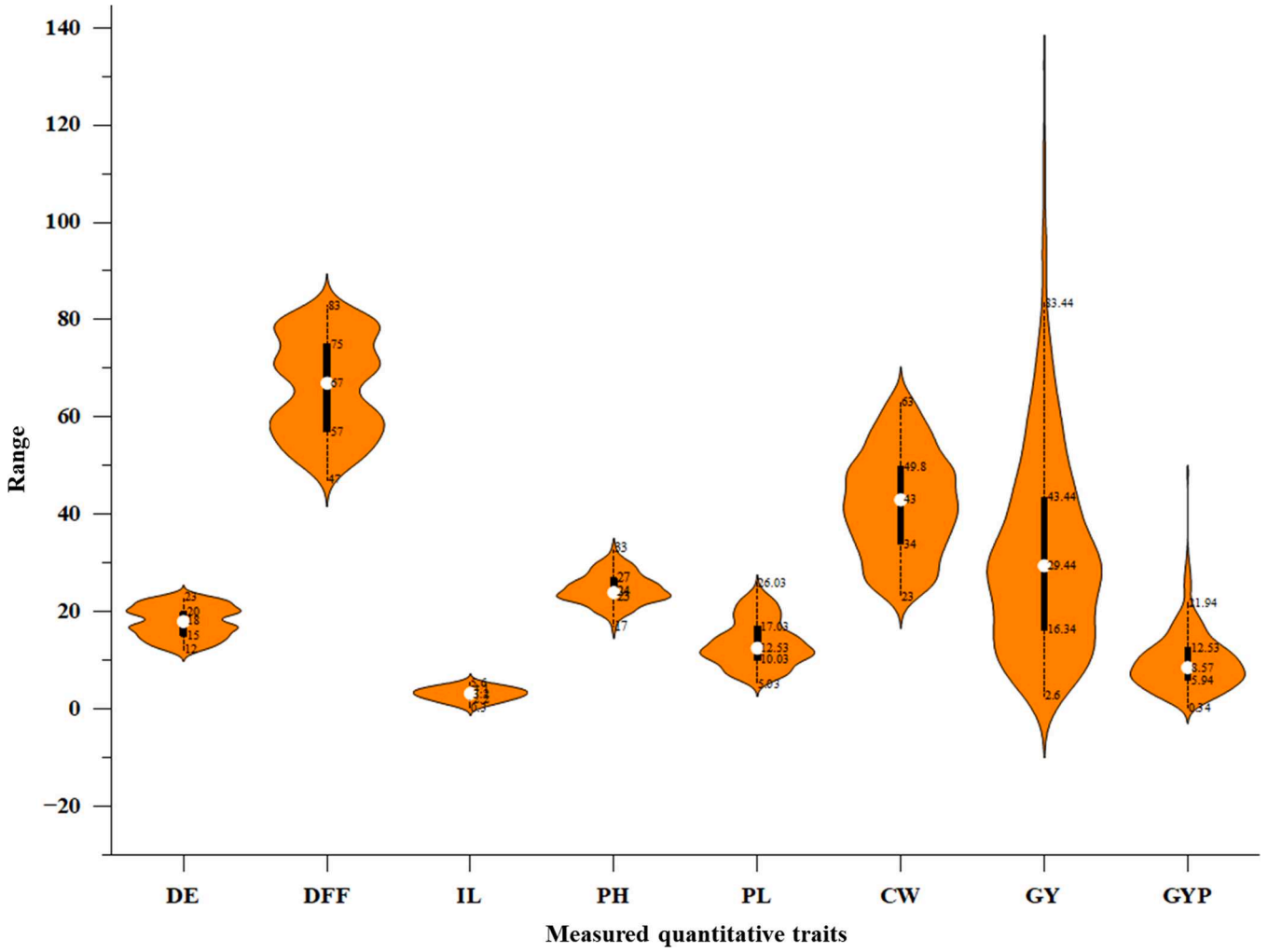

Fig. 1. Violin plots depicting the distribution of various agronomic traits in the studied population. DE: days to emergence, DFF: days to 50 % flowering, IL: internode length, pH: plant height, PL: petiole length, CW: canopy width, GY: grain yield, GYP: grain yield per plot.

correlations are depicted in blue, with the colour's intensity corresponding to the correlation's magnitude (Fig. 2a). Diagonal cells contain the value 1, indicating perfect self-correlation. The heatmap colour scale on the right ranges from −1.0 (strong -ve correlation) to 1.0 (strong +ve correlation). Key correlations include strong positive relationships between DE and DFF ($r = 0.85$; $p = 0.017$), pH ($r = 0.75$; $p = 0.021$) and PL ($r = 0.75$; $p = 0.027$). Petiole length was positively correlated with DFF ($r = 0.89$; $p = 0.01$) and pH ($r = 0.86$; $p = 0.011$). Internode length was negatively correlated with DE ($r = -0.23$; $p = 0.048$) and DFF ($r = -0.24$; $p = 0.05$) (Fig. 2a).

The circular chord diagram (CCD) effectively visualizes the complex interrelationships among traits (Fig. 2b). Red chords represent positive correlations, while blue chords represent negative correlations, indicating an inverse relationship between traits. The colour intensity reflects the strength of the correlation. Darker colours suggest stronger correlations, while lighter colours indicate weaker relationships. Thick red chords between DE and DFF indicate a strong positive relationship, while thin blue chords between IL and other traits indicate weaker negative correlations. Fig. 2b reveals key developmental and productivity patterns, with significant +ve correlations among phenological and growth traits and weaker or inverse relationships for structural traits like internode length. These insights can guide breeders and researchers in optimizing multi-trait selection strategies.

Table 7
Mean values growth and yield parameters of 365 Bambara groundnut genotypes.

Genotype	DE (days)	DFF (days)	IL (cm)	PH (cm)	PL (cm)	CW (cm)	GY (g plot^{-1})	GYP (g plant^{-1})
100SB16ANAM-C	13.4^{ijk}	55.8^{HIJKL}	2.54^{FGHI}	22.6^{xy}	11.83^{zA}	41.8st^{uvwxyz}	65.2^{ghijklmno}	18.18^{m}
20ACC118CIVB	20.6^{abcd}	72.6^{klmn}	2.32$^{H\ I\ J\ K}$	26.4^{ikl}	16.43$^{\circ p}$	39.2 ^{wxyzABC}	17.2$^{l1m1n1\circ 1p1q1r1s1t1u1v1w1\times 1y1z1A1B1C1D1E1F1}$	6.2$^{J1K1L1M1N1\circ 1P1Q1R1S1T1U1}$
ANKPA4	21.8^{ab}	77.2^{cdefgh}	2.78^{CDEFG}	23.8^{tuv}	18.63^{jk}	43.2rs^{tuvw}	7.6^{D1E1F1G1H1I1J1}	3.06$^{n2\circ 2p2q2r2s2t2}$
BURKINA	15.8^{efghijk}	58.6^{EFGHI}	4.1^{nopqrs}	22.8^{wx}	9.43^{CD}	41.6st^{uvwxyzA}	7.6^{D1E1F1G1H1I1J1}	4.4^{b2c2d2e2f2g2h2i2j2k2l2}
DIP-C	21.4^{abc}	78.4^{bcde}	1.58ST^{UV}	28.2 g	19.23^{gij}	49.4^{iklmno}	34.8^{KLMNOPQRSTUVWXYZa1b1c1d1e1f1g1}	11.6^{HIJKLMNOPQRSTUV}
DODR	19.6^{abcdef}	71.2^{lmnop}	2.3^{HIJKL}	25.2^{nop}	14.63st^{uv}	42.4rs^{tuvwx}	27.2$^{VWXYZa1b1c1d1e1f1g1h1i1j1k1l1m1n1\circ 1p1q1}$	8.66^{p1q1r1s1t1u1v1w1}
EXSOCOTO	18.2^{bcdefgh}	66.6^{qrstuvwxyz}	2.36^{HIJK}	23.8^{tuv}	14.43st^{uv}	42.8rs^{tuvw}	36.8^{HIJKLMNOPQRSTUVWXYZa1b1c1d1}	10.34^{XYZa1b1c1d1e1f1g1h1i1j1}
GHC37105	22.6^{a}	80.6^{abc}	0.86 g^{1h1}	29.8^{e}	22.83^{cd}	40.2^{uvwxyzAB}	54.4$^{\circ pqrstuvwxyzAB}$	14.54rs^{tuvw}
IITA686	22.2^{ab}	79^{abcde}	3.24^{xyzAB}	29.8^{e}	19.83^{ghi}	37.2^{zABCDEFG}	52.8^{pqrstuvwxyzABCDE}	17.5^{mno}
IITA686/LunT-257–216	23^{a}	80^{abcd}	0.9 g^{1h1}	29^{f}	21.03^{f}	25$^{\circ PQ}$	63.44^{ijklmnop}	16.87^{nop}
IITA686/LunT-258–217	15^{ghijk}	56^{HIJKL}	2.8^{CDEFG}	22^{z}	8.03^{E}	45$^{\circ pqrst}$	8^{C1D1E1F1G1H1I1J1}	3.37$^{k2l2m2n2\circ 2p2q2r2}$
IITA686/LunT-259–218	15^{ghijk}	57^{GHIJK}	2.8^{CDEFG}	22^{z}	10.03^{C}	34^{DFGHIJ}	5.8^{F1G1H1I1J1}	3.6$^{h2i2j2k2l2m2n2\circ 2p2q2}$
IITA686/LunT-260–219	20^{abcde}	72^{klmno}	0.9 g^{1h1}	26^{lm}	13.03^{x}	51^{hijklm}	30.6^{PQRSTUVWXYZa1b1c1d1e1f1g1h1i1j1k1}	7.82$^{w1\times 1y1z1A1B1C1D1E1F1G1}$
IITA686/LunT-261–220	20^{abcde}	72^{klmno}	3.5^{uvwxy}	26^{lm}	14.03^{v}	54^{efghi}	42.6^{BCDEFGHIJKLMNOP}	10.82^{RSTUVWXYZa1b1c1d1e1}
IITA686/LunT-262–221	19^{abcdefg}	69^{nopqr}	2.6^{EFGHI}	25^{pq}	12.03^{z}	51^{hijklm}	28.6ST^{UVWXYZa1b1c1d1e1f1g1h1i1j1k1l1m1n1}	10.02^{b1d1e1f1g1h1i1j1k1}
IITA686/LunT-264–222	17^{defghij}	60^{CDEFGH}	1.1^{WYZa1b1c1d1e1f1g1h1}	23^{wx}	8.03^{E}	32^{HIJKL}	13.32$^{u1w1\times 1y1z1A1B1C1D1E1F1G1H1I1J1}$	10.6^{TVWXYZa1b1c1d1e1f1}
IITA686/LunT-265–223	20^{abcde}	70^{mnopq}	2.7^{DEFGH}	25^{pq}	14.03^{v}	44^{qrstuv}	5.65^{F1G1H1I1J1}	2.55^{q2r2s2t2u2v2}
IITA686/LunT-266–224	20^{abcde}	70^{mnopq}	2.1^{JKLMN}	25^{pq}	15.03st	56^{cdefg}	3.44^{I1J1}	2.67^{p2q2r2s2t2u2v2}
IITA686/LunT-269–225	17^{defghij}	63^{zABCD}	3.7st^{uvw}	24^{t}	10.03^{C}	35^{CDEFGHI}	35.51^{IJKLMNOPQRSTUVWXYZa1b1c1d1e1}	9.23$^{j1k1l1m1n1\circ 1p1q1r1s1t1u1v1}$
IITA686/LunT-271–226	17^{defghij}	60^{CDEFGH}	3.9^{qrstu}	24^{t}	13.03^{x}	26^{NOPQ}	7.44^{D1E1F1G1H1I1J1}	4.07 g^{2h2i2j2k2l2m2n2}
IITA686/LunT-274–227	12^{k}	49$^{\circ PQRS}$	5.2^{de}	18^{E}	6.03^{G}	38^{xyzABCD}	27.51$^{VWXYZa1b1c1d1e1f1g1h1i1j1k1l1m1n1\circ 1p1}$	6.53$^{I1J1K1L1M1N1\circ 1P1}$
IITA686/LunT-280–228	17^{defghij}	47^{PQS}	3.5^{uvwxy}	16^{G}	6.03^{G}	43rs^{tuvw}	27.51$^{VWXYZa1b1c1d1e1f1g1h1i1j1k1l1m1n1\circ 1p1}$	6.53$^{I1J1K1L1M1N1\circ 1P1}$
IITA686/LunT-283–229	12^{k}	49$^{\circ PQRS}$	5.2^{de}	16^{G}	5.03^{H}	63^{a}	27.51$^{VWXYZa1b1c1d1e1f1g1h1i1j1k1l1m1n1\circ 1p1}$	6.53$^{H1I1J1K1L1M1N1\circ 1P1}$
IITA686/LunT-284–230	14^{hijk}	54^{JKLMN}	4.5^{hijklmn}	24^{t}	7.03^{F}	40^{uvwxyzAB}	13.53$^{t1u1w1\times 1y1z1A1B1C1D1E1F1G1H1I1J1}$	5.54$^{N1\circ 1P1Q1R1S1T1U1V1W1\times 1Y1Z1a2b2}$
IITA686/LunT-289–231	14^{hijk}	55^{IJKLM}	3.7^{b}	22^{z}	10.03^{C}	56^{cdefg}	20.4$^{i1j1k1l1m1n1\circ 1p1q1r1s1t1u1v1w1\times 1y1z1A1B1C1}$	5.8$^{M1N1\circ 1P1Q1R1S1T1U1V1W1\times 1Y1Z1}$
IITA686/LunT-291–232	20^{abcde}	71^{lmnop}	2.9^{BCDEF}	26^{lm}	15.03st	28^{LMNOP}	6.91^{E1F1G1H1I1J1}	1.94$^{u2v2w2\times 2}$
IITA686/LunT-292–233	22^{ab}	78^{bcdef}	2.2^{IJKLM}	28 g	19.03^{j}	51^{hijklm}	44.91^{xyzABCDEFGHIJKLM}	11.44^{JKLMNOPQRSTUVWX}
IITA686/LunT-293–234	22^{ab}	79^{abcde}	3.9^{qrstu}	29^{f}	20.03 g	57^{bcdef}	15.47$^{p1q1r1s1t1u1v1w1\times 1y1z1A1B1C1D1E1F1G1H1I1}$	11.35^{KLMNOPQRSTUVWXYZ}
IITA686/LunT-295–235	14^{hijk}	53^{KLMNO}	4.8^{efghi}	21^{A}	7.03^{F}	36^{BCDEFGH}	25.53$^{Za1b1d1e1f1g1h1i1j1k1l1m1n1\circ 1p1q1r1s1t1u1}$	12.84^{zABCDEFG}
IITA686/LunT-296–236	22^{ab}	79^{abcde}	1.4^{TUVWXY}	28 g	19.03^{j}	52^{ghijkl}	29.44^{QRSTUVWXYZa1b1c1d1e1f1g1h1i1j1k1l1}	6.57$^{H1I1J1K1L1M1N1\circ 1}$
IITA686/LunT-297–237	21^{abcd}	77^{cdefghi}	2.5^{FGHIJ}	26^{lm}	19.03^{j}	29^{KLMNO}	10.91^{y1z1A1B1C1D1E1F1G1H1I1J1}	5.94$^{M1N1\circ 1P1Q1R1S1T1U1V1W1\times 1}$
IITA686/LunT-298–238	20^{abcde}	71^{lmnop}	3.2^{xyzABC}	26^{lm}	15.03st	38^{xyzABCD}	10.91^{y1z1A1B1C1D1E1F1G1H1I1J1}	3.94 g$^{2h2i2j2k2l2m2n2\circ 2}$
IITA686/LunT-300–239	17^{defghij}	78^{bcdef}	1.8^{MNOPQRST}	28 g	19.03^{j}	50^{ijklmn}	62.6^{ijklmnopq}	12.52^{DEFGHIJKLM}
IITA686/LunT-301–240	21^{abcd}	76^{defghijk}	2.8^{CDEFG}	27^{hi}	10.03^{C}	63^{a}	59.53^{klmnopqrstu}	13.84^{tuvwxyzAB}
IITA686/LunT-302–241	14^{hijk}	54^{JKLMN}	4.6^{ghijklm}	20^{C}	6.03^{G}	49^{klmnop}	27.51$^{VWXYZa1b1c1d1e1f1g1h1i1j1k1l1m1n1\circ 1p1}$	6.53$^{H1I1J1K1L1M1N1\circ 1P1}$
IITA686/LunT-303–242	13^{jk}	52^{LMNO}	4.8^{efghi}	21^{A}	8.03^{E}	48^{lmnopq}	29.51^{QRSTUVWXYZa1b1c1d1e1f1g1h1i1j1k1l1}	8.53$^{q1r1s1t1u1v1w1\times 1y1z1}$
IITA686/LunT-305–243	22^{ab}	79^{abcde}	2^{KLMNOPQ}	30^{e}	22.03^{e}	32^{HIJKL}	58.6^{lmnopqrstuv}	20.02^{kl}
IITA686/LunT-306–244	13^{jk}	51^{MNOP}	4.9^{defgh}	20^{C}	7.03^{F}	39^{wxyzABC}	8.6^{C1D1E1F1G1H1I1J1}	3.32$^{l2m2n2\circ 2p2q2r2}$
IITA686/LunT-309–245	14^{hijk}	55^{IJKLM}	4.6^{ghijklm}	21^{A}	8.03^{E}	58^{bcde}	22.91$^{f1g1h1i1j1k1l1m1n1\circ 1p1q1r1s1t1u1v1w1\times 1y1z1}$	7.24^{C1D1E1F1G1H1I1J1K1L1}
IITA686/LunT-310–246	16^{efghijk}	56^{HIJKL}	2.9^{BCDEF}	21^{A}	8.03^{E}	25$^{\circ PQ}$	39.7^{FGHIJKLMNOPQRSTUV}	14.84rs^{t}
IITA686/LunT-312–247	15^{ghijk}	56^{HIJKL}	4.6^{ghijklm}	22^{z}	10.03^{C}	34^{DFGHIJ}	49.51^{tuvwxyzABCDEFG}	17.53^{mno}
IITA686/LunT-313–248	19^{abcdefg}	69^{nopqr}	3.1^{yzABCD}	25^{pq}	14.03^{v}	63^{a}	9.44^{B1C1D1E1F1G1H1I1J1}	7.37^{y1z1A1B1C1D1E1F1G1H1I1J1}
IITA686/LunT-314–249	19^{abcdefg}	69^{nopqr}	3^{ABCDE}	24^{t}	13.03^{x}	46^{nopqrs}	9.53^{B1C1D1E1F1G1H1I1J1}	1.34$^{w2\times 2y2z2A2}$
IITA686/LunT-316–250	19^{abcdefg}	68$^{\circ pqrs}$	0.9^{b1g1h1}	24^{t}	18.03^{kl}	48^{lmnopq}	6.91^{E1F1G1H1I1J1}	1.94$^{t2u2v2w2\times 2}$
IITA686/LunT-318–251	15^{ghijk}	57^{GHIJK}	1.3^{UVWXYZa1b1}	23^{wx}	12.03^{z}	54^{efghi}	5.84^{F1G1H1I1J1}	1.53$^{v2w2\times 2y2z2}$
IITA686/LunT-319–252	20^{abcde}	70^{mnopq}	2.1^{JKLMN}	22^{z}	14.03^{v}	56^{cdefg}	25.8$^{Za1b1d1e1f1g1h1i1j1k1l1m1n1\circ 1p1q1r1s1t1u1}$	7.43$^{\times 1y1z1A1B1C1D1E1F1G1H1I1}$
IITA686/LunT-320–253	23^{a}	81^{abc}	1.4^{TUVWXY}	30^{e}	22.03^{e}	37^{ABCDEFG}	6.91^{E1F1G1H1I1J1}	1.94$^{t2u2v2w2\times 2}$
IITA686/LunT-321–254	17^{defghij}	62^{ABCDEF}	3.8rs^{tuv}	24^{t}	13.03^{x}	61^{ab}	53.51$^{\circ pqrstuvwxyzABC}$	19.53^{l}
IITA686/LunT-322–255	22^{ab}	79^{abcde}	1.8^{MNOPQRST}	23^{wx}	21.03^{f}	40^{uvwxyzAB}	18.9$^{1k1l1m1n1\circ 1p1q1r1s1t1u1v1w1\times 1y1z1A1B1C1D1E1}$	5.94$^{M1N1\circ 1P1Q1R1S1T1U1V1W1\times 1}$
IITA686/LunT-324–256	22^{ab}	78^{bcdef}	2.8^{CDEFG}	29^{f}	19.03^{j}	51^{hijklm}	24.6$^{b1d1e1f1g1h1i1j1k1l1m1n1\circ 1p1q1r1s1t1u1v1w1}$	6.32$^{I1J1K1L1M1N1\circ 1P1Q1R1S1T1U1}$
IITA686/LunT-326–257	16^{efghijk}	59^{DEFGHI}	4^{pqrst}	23^{wx}	12.03^{z}	44^{qrstuv}	39.51^{FGHIJKLMNOPQRSTUV}	10.53^{VWXYZa1b1c1d1e1f1g1}
IITA686/LunT-327–258	18^{bcdefgh}	65rs^{tuvwxyzAB}	1.3^{UVWXYZa1b1c1}	24^{t}	12.03^{z}	25$^{\circ PQ}$	30.91$^{\circ PQRSTUVWXYZa1b1c1d1e1f1g1h1i1j1k1}$	9.94^{d1e1f1g1h1i1j1k1l1}
IITA686/LunT-330–259	18^{bcdefgh}	78^{bcdef}	2.2^{IJKLM}	29^{f}	21.03^{f}	43rs^{tuvw}	45.44^{wxyzABCDEFGHIJK}	7.77$^{w1\times 1y1z1A1B1C1D1E1F1G1}$
IITA686/LunT-332–260	22^{ab}	78^{bcdef}	2.1^{JKLMN}	28 g	19.03^{j}	41^{tuvwxyzA}	15.6$^{p1q1r1s1t1u1v1w1\times 1y1z1A1B1C1D1E1F1G1H1I1}$	4.84$^{W1\times 1Y1Z1a2b2c2d2e2f2g2}$

(*continued on next page*)

Table 7 (*continued*)

Genotype	DE (days)	DFF (days)	IL (cm)	PH (cm)	PL (cm)	CW (cm)	GY (g plot^{-1})	GYP (g plant^{-1})
IITA686/LunT-333–261	13^{jk}	53^{KLMNO}	4.7^{fghijkl}	20^{C}	12.03^{z}	41^{tuvwxyzA}	27.51$^{VWXYZa1b1c1d1e1f1g1h1i1j1k1l1m1n1∘1p1}$	6.53$^{H1I1J1K1L1M1N1∘1P1}$
IITA686/LunT-334–262	15^{ghijk}	56^{HIJKL}	2^{KLMNOPQ}	20^{C}	10.03^{C}	44^{qrstuv}	19.53$^{j1k1l1m1n1∘1p1q1r1s1t1u1v1w1×1y1z1A1B1C1D1}$	14.84rs^{t}
IITA686/LunT-335–263	14^{hijk}	55^{IJKLM}	1.7^{NPQRSTU}	22^{z}	7.03^{F}	38^{xyzABCD}	31.51^{NOPQRSTUVWXYZa1b1c1d1e1f1g1h1i1j1}	19.53^{l}
IITA686/LunT-337–264	16^{efghijk}	59^{DEFGHI}	4.1^{nopqrs}	23^{wx}	11.03^{B}	41^{tuvwxyzA}	32.6^{MNOPQRSTUVWXYZa1b1c1d1e1f1g1h1i1}	8.32$^{r1s1t1u1v1w1×1y1z1A1B1C1}$
IITA686/LunT-338–265	20^{abcde}	70^{mnopq}	3.5^{uvwxy}	25^{pq}	13.03^{x}	38^{xyzABCD}	11.9$^{×1y1z1A1B1C1D1E1F1G1H1I1J1}$	4.7^{Y1Z1a2b2c2d2e2f2g2h2}
IITA686/LunT-340–267	13^{jk}	50^{NOPQRS}	5^{defg}	18^{E}	6.03^{G}	33^{GHIJK}	27.51$^{VWXYZa1b1c1d1e1f1g1h1i1j1k1l1m1n1∘1p1}$	6.53$^{H1I1J1K1L1M1N1∘1P1}$
IITA686/LunT-341–268	23^{a}	80^{abcd}	1.6^{QSTUV}	31^{d}	22.03^{e}	30^{JKLMN}	59.44^{klmnopqrstu}	12.57^{CDEFGHIJ}
IITA686/LunT-344–269	23^{a}	82^{ab}	0.7^{h1}	33^{b}	24.03^{b}	37^{ABCDEFG}	26.91$^{WXYZa1b1c1d1e1f1g1h1i1j1k1l1m1n1∘1p1q1r1}$	8.64$^{p1q1r1s1t1u1v1w1×1}$
IITA686/LunT-345–270	17^{defghij}	60^{CDEFGH}	3.4^{vwxyzA}	23^{wx}	11.03^{B}	52^{ghijkl}	17.8$^{l1m1n1∘1p1q1r1s1t1u1v1w1×1y1z1A1B1C1D1E1F1}$	8.4$^{q1r1s1t1u1v1w1×1y1z1A1B1C1}$
IITA686/LunT-348–271	12^{k}	79abcde	3.8rs^{tuv}	30^{e}	22.03^{e}	44^{qrstuv}	76.6^{efg}	19.32l
IITA686/LunT-350–272	13^{jk}	52^{LMNO}	4.8^{efghi}	25^{pq}	6.03^{G}	47^{mnopqr}	27.51$^{VWXYZa1b1c1d1e1f1g1h1i1j1k1l1m1n1∘1p1}$	6.53$^{H1I1J1K1L1M1N1∘1P1}$
IITA686/LunT-351–273	19^{abcdefg}	68$^{∘pqrs}$	3.2^{xyzABC}	25^{pq}	16.03^{pq}	61^{ab}	31.51^{NOPQRSTUVWXYZa1b1c1d1e1f1g1h1i1j1}	8.53$^{q1r1s1t1u1v1w1×1y1z1}$
IITA686/LunT-352–274	18^{bcdefgh}	64^{svwxyzABC}	4^{pqrst}	23^{wx}	12.03^{z}	51^{hijklm}	8.91^{C1D1E1F1G1H1I1J1}	3.94 g$^{2h2i2j2k2l2m2n2∘2}$
IITA686/LunT-353–275	20^{abcde}	70^{mnopq}	3^{ABCDE}	25^{pq}	10.03^{C}	36^{BCDEFGH}	29.53^{QRSTUVWXYZa1b1c1d1e1f1g1h1i1j1k1l1}	8.53$^{q1r1s1t1u1v1w1×1y1z1}$
IITA686/LunT-354–276	23^{a}	80^{abcd}	2.9^{BCDEF}	30^{e}	22.03^{e}	40^{uvwxyzAB}	8.6^{C1D1E1F1G1H1I1J1}	5.32$^{P1U1V1W1×1Y1Z1a2b2c2d2e2}$
IITA686/LunT-356–277	23^{a}	82^{ab}	3.5^{uvwxy}	33^{b}	23.03^{c}	47^{mnopqr}	26.6$^{XYZa1b1c1d1e1f1g1h1i1j1k1l1m1n1∘1p1q1r1s1}$	9.32 g$^{1i1j1k1l1m1n1∘1p1q1r1s1t1}$
IITA686/LunT-357–278	19^{abcdefg}	69^{nopqr}	3.1^{yzABCD}	28 g	14.03^{v}	32^{HIJKL}	36.91^{HIJKLMNOPQRSTUVWXYZa1b1c1d1}	11.94^{GHIJKLMNOPQR}
IITA686/LunT-359–279	22^{ab}	77^{cdefghi}	3.9^{qrstu}	27^{hi}	17.03^{no}	48^{lmnopq}	12.91$^{w1×1y1z1A1B1C1D1E1F1G1H1I1J1}$	3.94 g$^{2h2i2j2k2l2m2n2∘2}$
IITA686/LunT-360–280	19^{abcdefg}	69^{nopqr}	3.7st^{uvw}	25^{pq}	14.03^{v}	42st^{uvwxy}	50.53rs^{tuvwxyzABCDEF}	7.84$^{w1×1y1z1A1B1C1D1E1F1G1}$
IITA686/LunT-362–281	17^{defghij}	62^{ABCDEF}	3.9^{qrstu}	23^{wx}	11.03^{B}	48^{lmnopq}	29.53^{QRSTUVWXYZa1b1c1d1e1f1g1h1i1j1k1l1}	6.34$^{I1J1K1L1M1N1∘1P1Q1R1S1T1U1}$
IITA686/LunT-363–282	20^{abcde}	71^{lmnop}	2.9^{BCDEF}	25^{pq}	14.03^{v}	54^{efghi}	27.51$^{VWXYZa1b1c1d1e1f1g1h1i1j1k1l1m1n1∘1p1}$	6.53$^{H1I1J1K1L1M1N1∘1P1}$
IITA686/LunT-364–283	12^{k}	70^{mnopq}	2.2^{IJKLM}	25^{pq}	14.03^{v}	43rs^{tuvw}	16.21$^{n1∘1p1q1r1s1t1u1v1w1×1y1z1A1B1C1D1E1F1G1}$	6.94^{D1E1F1G1H1I1J1K1L1M1}
IITA686/LunT-365–284	22^{ab}	79^{abcde}	2.1^{JKLMN}	29^{f}	21.03^{f}	26^{NOPQ}	18.l$^{1m1n1∘1p1q1r1s1t1u1v1w1×1y1z1A1B1C1D1E1F1}$	8.84$^{l1m1n1∘1p1q1r1s1t1u1v1w1}$
IITA686/LunT-366–285	15^{ghijk}	79^{abcde}	2.3^{HIJKL}	29^{f}	21.03^{f}	48^{lmnopq}	7.53^{D1E1F1G1H1I1J1}	0.84$^{×2z2A2}$
IITA686/LunT-367–286	18^{bcdefgh}	80^{abcd}	1.1^{WXYZa1b1c1d1e1f1g1h1}	29^{f}	20.03 g	28^{LMNOP}	69.51^{fghijkl}	48.53^{a}
IITA686/LunT-369–287	20^{abcde}	72^{klmno}	2.7^{DEFGH}	26^{lm}	15.03st	41^{tuvwxyzA}	16.91$^{m1n1∘1p1q1r1s1t1u1v1w1×1y1z1A1B1C1D1E1F1G1}$	4.64^{Y1Z1a2b2c2d2e2f2g2h2i2}
IITA686/LunT-370–288	22^{ab}	77^{cdefghi}	3.4^{vwxyzA}	27^{hi}	12.03^{z}	31^{IJKLM}	54.6$^{∘pqrstuvwxyzAB}$	13.86^{tuvwxyzAB}
IITA686/LunT-370–289	20^{abcde}	70^{mnopq}	3.1^{yzABCD}	25^{pq}	16.03^{pq}	63^{a}	9.75^{B1C1D1E1F1G1H1I1J1}	4.82$^{×1Y1Z1a2b2c2d2e2f2g2}$
IITA686/LunT-373–290	12^{k}	77^{cdefghi}	2.9^{BCDEF}	20^{C}	8.03^{E}	29^{KLMNO}	10.67^{z1A1B1C1D1E1F1G1H1I1J1}	2.84$^{∘2p2q2r2s2t2u2}$
IITA686/LunT-374–291	20^{abcde}	71^{lmnop}	5^{defg}	26^{lm}	15.03st	41^{tuvwxyzA}	24.91$^{a1b1d1e1f1g1h1i1j1k1l1m1n1∘1p1q1r1s1t1u1v1w1}$	6.44$^{I1J1K1L1M1N1∘1P1Q1R1S1T1U1}$
IITA686/LunT-375–292	16^{efghijk}	57^{GHIJK}	4.3^{lmnopq}	22^{z}	11.03^{B}	50^{ijklmn}	33.51^{KLMNOPQRSTUVWXYZa1b1c1d1e1f1g1h1}	12.43^{EFGHIJKLMN}
IITA686/LunT-377–293	14^{hijk}	58^{FGHIJ}	4.2^{a}	23^{wx}	11.03^{B}	49^{klmnop}	29.51^{QRSTUVWXYZa1b1c1d1e1f1g1h1i1j1k1l1}	8.53$^{q1r1s1t1u1v1w1×1y1z1}$
IITA686/LunT-378–294	21^{abcd}	75^{efghijkl}	2.4^{GHIJK}	27^{hi}	15.03st	46^{nopqrs}	12.6$^{w1×1y1z1A1B1C1D1E1F1G1H1I1J1}$	7.32^{z1C1D1E1F1G1H1I1J1K1}
IITA686/LunT-379–295	22^{ab}	80^{abcd}	3.1^{yzABCD}	29^{f}	20.03 g	63^{a}	56.91^{mnopqrstuvwx}	11.93^{GHIJKLMNOPQR}
IITA686/LunT-381–296	19^{abcdefg}	68$^{∘pqrs}$	3.2^{xyzABC}	25^{pq}	13.03^{x}	63^{a}	29.51^{QRSTUVWXYZa1b1c1d1e1f1g1h1i1j1k1l1}	8.53$^{q1r1s1t1u1v1w1×1y1z1}$
IITA686/LunT-384–297	17^{defghij}	61^{BCDEFG}	3.9^{qrstu}	24^{t}	12.03^{z}	41^{tuvwxyzA}	18.71$^{k1l1m1n1∘1p1q1r1s1t1u1v1w1×1y1z1A1B1C1D1E1}$	5.55$^{N1∘1P1Q1R1S1T1U1V1W1×1Y1Z1a2b2}$
IITA686/LunT-385–298	15^{ghijk}	57^{GHIJK}	4.3^{lmnopq}	22^{z}	8.03^{E}	37^{ABCDEFG}	29.51^{QRSTUVWXYZa1b1c1d1e1f1g1h1i1j1k1l1}	5.53$^{N1∘1P1Q1R1S1T1U1V1W1×1Y1Z1a2b2c2}$
IITA686/LunT-386–299	22^{ab}	79^{abcde}	2.1^{JKLMN}	28 g	19.03^{j}	33^{GHIJK}	58.6^{lmnopqrstuv}	20.02^{kl}
IITA686/LunT-386–300	17^{defghij}	63^{yzABCD}	3.7st^{uvw}	23^{wx}	12.03^{yz}	47^{mnopqr}	43.44^{zABCDEFGHIJKLMN}	16.07^{pq}
IITA686/LunT-387–301	17^{defghij}	60^{CDEFGH}	0.9^{b1c1g1h1}	23^{wx}	12.03^{yz}	63^{a}	25.44$^{Za1b1d1e1f1g1h1i1j1k1l1m1n1∘1p1q1r1s1t1u1}$	7.37^{y1z1A1B1C1D1E1F1G1H1I1J1}
IITA686/LunT-388–302	15^{ghijk}	57^{GHIJK}	4.5^{hijklmn}	22^{z}	10.03^{C}	38^{xyzABCD}	13.53$^{t1u1w1×1y1z1A1B1C1D1E1F1G1H1I1J1}$	0.44^{A2}
IITA686/LunT-389–303	23^{a}	81^{abc}	3.8rs^{tuv}	31^{d}	24.03^{b}	34^{DFGHIJ}	41.51^{CDEFGHIJKLMNOPQ}	11.23$^{∘PQRSTUVWXYZa1b1}$
IITA686/LunT-390–304	14^{hijk}	53^{KLMNO}	4^{pqrst}	20^{C}	7.03^{F}	33^{GHIJK}	55.53^{nopqrstuvwxyz}	8.84$^{l1m1n1∘1p1q1r1s1t1u1v1w1}$
IITA686/LunT-392–305	23^{a}	81^{abc}	1.6^{QRSTUV}	30^{e}	21.03^{f}	43rs^{tuvw}	12.6$^{w1×1y1z1A1B1C1D1E1F1G1H1I1J1}$	7.32^{z1A1C1D1E1F1G1H1I1J1K1}
IITA686/LunT-394–306	20^{abcde}	71^{lmnop}	1.3^{UVWXYZa1b1c1d1}	26^{lm}	12.03^{yz}	51^{hijklm}	8.45^{C1D1E1F1G1H1I1J1}	2.07^{s2t2u2v2w2}
IITA686/LunT-395–307	20^{abcde}	72^{klmno}	5^{defg}	26^{lm}	15.03st	43rs^{tuvw}	17.88$^{l1m1n1∘1p1q1r1s1t1u1v1w1×1y1z1A1B1C1D1E1F1}$	4.84$^{W1×1Y1Z1a2b2c2d2e2f2g2}$
IITA686/LunT-396–308	20^{abcde}	70^{mnopq}	1.3^{UVWXYZa1b1c1d1e1}	25^{pq}	14.03^{v}	60^{abc}	31.51^{NOPQRSTUVWXYZa1b1c1d1e1f1g1h1i1j1}	8.53$^{q1r1s1t1u1v1w1×1y1z1}$
IITA686/LunT-397–309	17^{defghij}	62^{ABCDEF}	1.4^{TUVWXY}	24^{t}	10.03^{C}	26^{NOPQ}	35.51^{IJKLMNOPQRSTUVWXYZa1b1c1d1e1}	10.53^{VWXYZa1b1c1d1e1f1g1}
IITA686/LunT-398–310	23^{a}	80^{abcd}	0.9^{b1c1d1g1h1}	30^{e}	22.03^{e}	43rs^{tuvw}	45.44^{wxyzABCDEFGHIJK}	25.37^{f}
IITA686/LunT-399–311	15^{ghijk}	81^{abc}	2.9^{BCDEF}	31^{d}	22.03^{e}	63^{a}	16.06$^{∘1p1q1r1s1t1u1v1w1×1y1z1A1B1C1D1E1F1G1}$	6.02$^{L1M1N1∘1P1Q1R1S1T1U1V1W1}$
IITA686/LunT-400–312	18^{bcdefgh}	67^{pqrstuv}	3.3^{wxyzAB}	23^{wx}	11.03^{B}	28^{LMNOP}	26.91$^{WXYZa1b1c1d1e1f1g1h1i1j1k1l1m1n1∘1p1q1r1}$	11.94^{GHIJKLMNOPQR}
IITA686/LunT-402–313	17^{defghij}	62^{ABCDEF}	4.8^{efghi}	24st	12.03^{yz}	37^{ABCDEFG}	22.6 g$^{1h1i1j1k1l1m1n1∘1p1q1r1s1t1u1v1w1×1y1z1A1}$	8.02$^{v1w1×1y1z1A1B1C1D1E1}$
IITA686/LunT-403–314	20^{abcde}	73^{ijklmn}	0.8 g^{1h1}	26^{lm}	12.03^{yz}	32^{HIJKL}	5.53^{F1G1H1I1J1}	0.34^{A2}
IITA686/LunT-403–315	17^{defghij}	60^{CDEFGH}	2.5^{FGHIJ}	23^{wx}	20.03 g	32^{HIJKL}	64.44^{hijklmnop}	17.37^{mno}
IITA686/LunT-404–316	23^{a}	80^{abcd}	4.4^{iklmnop}	30^{e}	19.03^{j}	45$^{∘pqrst}$	16.38$^{n1∘1p1q1r1s1t1u1v1w1×1y1z1A1B1C1D1E1F1G1}$	5.73$^{M1N1∘1P1Q1R1S1T1U1V1W1×1Y1Z1a2}$

(*continued on next page*)

Table 7 (*continued*)

Genotype	DE (days)	DFF (days)	IL (cm)	PH (cm)	PL (cm)	CW (cm)	GY (g plot^{-1})	GYP (g plant^{-1})
IITA686/LunT-407–317	23^{a}	83^{a}	2.6^{EFGHI}	31^{d}	22.03^{e}	43rs^{tuvw}	8.86^{C1D1E1F1G1H1I1J1}	5.32$^{P1Q1U1V1W1\times1Y1Z1a2b2c2d2e2f2}$
IITA686/LunT-408–318	17^{defghij}	61^{BCDEFG}	3.1^{yzABCD}	23^{wx}	11.03^{B}	47^{mnopqr}	37.44^{GHIJKLMNOPQRSTUVWXYZa1}	8.17$^{s1t1u1v1w1\times1y1z1A1B1C1}$
IITA686/LunT-411–319	12^{k}	74^{fghijklm}	2.6^{EFGHI}	27^{hi}	17.03^{no}	47^{mnopqr}	37^{HIJKLMNOPQRSTUVWXYZa1b1}	11.37^{KLMNOPQRSTUVWXY}
IITA686/LunT-412–320	18^{bcdefgh}	64st^{vwxyzABC}	3.6^{tuvwx}	24st	12.03^{yz}	37^{ABCDEFG}	27.51$^{VWXYZa1b1c1d1e1f1g1h1i1j1k1l1m1n1\circ1p1}$	6.53$^{H1I1J1K1L1M1N1\circ1P1}$
IITA686/LunT-415–321	15^{ghijk}	56^{HIJKL}	1.6^{QRSTUV}	21^{A}	8.03^{E}	48^{lmnopq}	73.53^{efghi}	25.54^{ef}
IITA686/LunT-416–322	13^{ijk}	69^{nopqr}	3.1^{yzABCD}	25^{npq}	12.03^{yz}	28^{LMNOP}	4.6^{G1H1I1J1}	3.32$^{k2l2m2n2\circ2p2q2r2}$
IITA686/LunT-417–323	17^{defghij}	79^{abcde}	2.2^{IJKLM}	28 g	20.03 g	44^{qrstuv}	24.6$^{b1d1e1f1g1h1i1j1k1l1m1n1\circ1p1q1r1s1t1u1v1w1}$	4.92$^{V1W1\times1Y1Z1a2b2c2d2e2f2g2}$
IITA686/LunT-419–324	19^{abcdefg}	68$^{\circ pqrs}$	3.3^{wxyzAB}	24st	12.03^{yz}	39^{wxyzABC}	73.53^{efghi}	17.34^{mno}
IITA686/LunT-420–325	17^{defghij}	61^{BCDEFG}	3.2^{xyzABC}	23^{wx}	12.03^{yz}	45$^{\circ pqrst}$	17.53$^{l1m1n1\circ1p1q1r1s1t1u1v1w1\times1y1z1A1B1C1D1E1F1}$	3.34$^{k2l2m2n2\circ2p2q2r2}$
IITA686/LunT-421–326	23^{a}	83^{a}	2.7^{DEFGH}	32^{c}	19.03^{ij}	56^{cdefg}	10.32^{A1B1C1D1E1F1G1H1I1J1}	4.53^{b2c2d2e2f2g2h2i2j2k2}
IITA686/LunT-422–327	23^{a}	80^{abcd}	0.7^{h1}	30^{e}	22.03^{e}	50^{ijklmn}	12.91$^{w1\times1y1z1A1B1C1D1E1F1G1H1I1J1}$	7.94$^{w1\times1y1z1A1B1C1D1E1F1}$
IITA686/LunT-423–328	15^{ghijk}	55^{IJKLM}	4.6^{ghijklm}	21^{A}	7.03^{F}	56^{cdefg}	15.53$^{p1q1r1s1t1u1v1w1\times1y1z1A1B1C1D1E1F1G1H1I1}$	12.84^{zABCDEFG}
IITA686/LunT-426–329	20^{abcde}	71^{lmnop}	4.1^{nopqrs}	26^{lm}	15.03st	36^{BCDEFGH}	44.91^{xyzABCDEFGHIJKLM}	11.44^{JKLMNOPQRSTUVWX}
IITA686/LunT-427–330	16^{efghijk}	75^{efghijkl}	3.9^{qrstu}	27^{hi}	16.03^{pqr}	49^{klmnop}	40.06^{FGHIJKLMNOPQRSTU}	14.02st^{uvwxy}
IITA686/LunT-428–331	19^{abcdefg}	81^{abc}	0.9^{b1c1d1e1g1h1}	30^{e}	22.03^{de}	56^{cdefg}	27.51$^{VWXYZa1b1c1d1e1f1g1h1i1j1k1l1m1n1\circ1p1}$	6.53$^{H1I1J1K1L1M1N1\circ1P1}$
IITA686/LunT-429–332	22^{ab}	79^{abcde}	2^{KLMNOPQ}	29^{f}	17.03^{no}	56^{cdefg}	10.06^{B1C1D1E1F1G1H1I1J1}	4.02 g$^{2h2i2j2k2l2m2n2\circ2}$
IITA686/LunT-430–333	20^{abcde}	70^{mnopq}	2.3^{HIJKL}	25^{nopq}	15.03st	43rs^{tuvw}	6.91^{E1F1G1H1I1J1}	1.94$^{t2u2v2w2\times2}$
IITA686/LunT-431–334	20^{abcde}	72^{klmno}	2.8^{CDEFG}	26^{lm}	15.03st	39^{wxyzABC}	31.51^{NOPQRSTUVWXYZa1b1c1d1e1f1g1h1i1j1}	10.53^{VWXYZa1b1c1d1e1f1g1}
IITA686/LunT-432–335	22^{ab}	77^{cdefghi}	2.3^{HIJKL}	28 g	17.03^{no}	34^{DFGHIJ}	10.6^{z1A1B1C1D1E1F1G1H1I1J1}	6.32$^{I1J1K1L1M1N1\circ1P1Q1R1S1T1U1}$
IITA686/LunT-433–336	17^{defghij}	61^{BCDEFG}	2.8^{CDEFG}	23^{wx}	11.03^{B}	28^{LMNOP}	48.91^{uvwxyzABCDEFGH}	22.94^{i}
IITA686/LunT-434–337	23^{a}	83^{a}	3.1^{yzABCD}	32^{c}	24.03^{b}	51^{hijklm}	30.91$^{\circ PQRSTUVWXYZa1b1c1d1e1f1g1h1i1j1k1}$	7.94$^{w1\times1y1z1A1B1C1D1E1F1}$
IITA686/LunT-436–338	15^{ghijk}	56^{HIJKL}	4.4^{iklmnop}	22^{z}	10.03^{C}	51^{hijklm}	18.91$^{k1l1m1n1\circ1p1q1r1s1t1u1v1w1\times1y1z1A1B1C1D1E1}$	7.94$^{w1\times1y1z1A1B1C1D1E1F1}$
IITA686/LunT-437–339	23^{a}	80^{abcd}	3.8rs^{tuv}	31^{d}	12.03^{yz}	33^{GHIJK}	44.81^{xyzABCDEFGHIJKLM}	10.37^{WXYZa1b1c1d1e1f1g1h1i1j1}
IITA686/LunT-438–340	20^{abcde}	71^{lmnop}	2.8^{CDEFG}	26^{lm}	15.03st	37^{ABCDEFG}	15.44^{b}	23.77^{hi}
IITA686/LunT-439–341	21^{abcd}	76^{defghijk}	3.2^{xyzABC}	27^{hi}	18.03^{kl}	49^{klmnop}	13.37$^{u1w1\times1y1z1A1B1C1D1E1F1G1H1I1J1}$	4.32^{d2e2f2g2h2i2j2k2l2m2}
IITA686/LunT-440–342	14^{hijk}	53^{KLMNO}	4.7^{fghijkl}	24st	9.03^{D}	49^{klmnop}	6.91^{E1F1G1H1I1J1}	1.94$^{t2u2v2w2\times2}$
IITA686/LunT-441–343	21^{abcd}	77^{cdefghij}	2.3^{HIJKL}	28 g	19.03^{ij}	33^{GHIJK}	19.44$^{j1k1l1m1n1\circ1p1q1r1s1t1u1v1w1\times1y1z1A1B1C1D1E1}$	8.07$^{u1v1w1\times1y1z1A1B1C1D1}$
IITA686/LunT-442–344	23^{a}	71^{lmnop}	2.9^{BCDEF}	26^{lm}	15.03st	27^{MNOPQ}	16.91$^{m1n1\circ1p1q1r1s1t1u1v1w1\times1y1z1A1B1C1D1E1F1G1}$	6.94^{D1E1F1G1H1I1J1K1L1M1}
IITA686/LunT-443–345	13^{ijk}	52^{LMNO}	4.8^{efghi}	21^{A}	8.03^{E}	26^{NOPQ}	10.6^{z1A1B1C1D1E1F1G1H1I1J1}	4.02 g$^{2h2i2j2k2l2m2n2\circ2}$
IITA686/LunT-444–346	19^{abcdefg}	68$^{\circ pqrs}$	3.1^{yzABCD}	25^{nopq}	15.03st	63^{a}	71.51^{fghij}	15.33^{qr}
KANO2	17.4^{cdefghi}	62.4^{ABCDE}	3.42^{vwxyz}	24st	12.83^{xy}	49.8^{ijklmn}	7.37^{D1E1F1G1H1I1J1}	3.88 g$^{2h2i2j2k2l2m2n2\circ2}$
KENYACAPSTONE	22.2^{ab}	80.6^{abc}	1.84^{MNOPQRS}	31^{d}	21.43^{ef}	38.8^{wxyzABC}	35.44^{IJKLMNOPQRSTUVWXYZa1b1c1d1e1f1}	13.37^{wxyzABCDEF}
LUNT	20.6^{abcd}	73.4^{hijklm}	3.06^{zABCD}	25.6^{mn}	15.23^{qs}	37.6^{yzABCDEFG}	16$^{\circ1p1q1r1s1t1u1v1w1\times1y1z1A1B1C1D1E1F1G1H1}$	5.46$^{N1\circ1P1Q1R1S1T1U1V1W1\times1Y1Z1a2b2c2d2}$
MOQ-4	20.6^{abcd}	74.8^{efghijkl}	4.3^{lmnopq}	26^{lm}	17.63^{lmn}	47.8^{mnopq}	47.2^{vwxyzABCDEFGHIJ}	12.1^{GHIJKLMNOP}
NAV4	19.8^{abcdef}	71.4^{lmno}	3.2^{xyzABC}	25.6^{mno}	14.23^{tv}	39.4^{vwxyzABC}	23.2$^{e1f1g1h1i1j1k1l1m1n1\circ1p1q1r1s1t1u1v1w1\times1y1}$	7.76$^{w1\times1y1z1A1B1C1D1E1F1G1}$
PONG-BR	21^{abcd}	73.8^{fhijklm}	4.4^{iklmnop}	27.2^{h}	21.43^{ef}	39^{wxyzABC}	96.2^{c}	26.48^{e}
PONG-CR	14.8^{ghijk}	63.2^{vwxyzABCD}	4.06$^{\circ pqrs}$	26^{lm}	17.83^{klm}	37.6^{yzABCDEFG}	16.8$^{m1n1\circ1p1q1r1s1t1u1v1w1\times1y1z1A1B1C1D1E1F1G1}$	6.66^{G1H1I1J1K1L1M1N1}
S19	19.6^{abcdef}	71^{lmnop}	5.16^{de}	22.2^{yz}	13.83^{vw}	52.2^{ghijkl}	61.2^{jklmnopqrst}	19.76^{l}
S19/Ankpa4–100–87	15^{ghijk}	56^{HIJKL}	3.8rs^{tuv}	22^{z}	9.03^{D}	35^{CDEFGHI}	61.6^{jklmnopqr}	15.02^{qrs}
S19/Ankpa4–101–88	13^{ijk}	52^{LMNO}	4.3^{lmnopq}	20^{C}	7.03^{F}	44^{qrstuv}	45.2^{xyzABCDEFGHIJKL}	17.52^{mno}
S19/Ankpa4–102–89	13^{ijk}	53^{KLMNO}	2.7^{DEFGH}	20^{C}	8.03^{E}	47^{mnopqr}	26.6$^{XYZa1b1c1d1e1f1g1h1i1j1k1l1m1n1\circ1p1q1r1s1}$	6.82^{F1G1H1I1J1K1L1M1}
S19/Ankpa4–103–90	17^{defghij}	60^{CDEFGH}	1.6^{QRSTUV}	24st	14.03^{v}	45$^{\circ pqrst}$	7.32^{D1E1F1G1H1I1J1}	3.42$^{j2k2l2m2n2\circ2p2q2r2}$
S19/Ankpa4–104–91	15^{ghijk}	80^{abcd}	3.5^{uvwxy}	29^{f}	22.03^{de}	56^{cdefg}	44.25^{zABCDEFGHIJKLM}	13.66^{uvwxyzABCD}
S19/Ankpa4–106–92	17^{defghij}	62^{ABCDEF}	5^{defg}	23^{wx}	11.03^{B}	35^{CDEFGHI}	26.91$^{WXYZa1b1c1d1e1f1g1h1i1j1k1l1m1n1\circ1p1q1r1}$	8.64$^{p1q1r1s1t1u1v1w1\times1}$
S19/Ankpa4–108–93	15^{ghijk}	77^{cdefghij}	3.6^{tuvwx}	28 g	19.03^{ij}	29^{KLMNO}	24.6$^{b1d1e1f1g1h1i1j1k1l1m1n1\circ1p1q1r1s1t1u1v1w1}$	6.32$^{I1J1K1L1M1N1\circ1P1Q1R1S1T1U1}$
S19/Ankpa4–10–9	13^{ijk}	52^{LMNO}	4^{pqrst}	21^{A}	9.03^{D}	29^{KLMNO}	38.6^{FGHIJKLMNOPQRSTUVWX}	7.72$^{w1\times1y1z1A1B1C1D1E1F1G1H1}$
S19/Ankpa4–1–1	22^{ab}	80^{abcd}	0.8 g^{1h1}	27^{hij}	12.03^{yz}	48^{lmnopq}	83.44^{de}	29.37^{c}
S19/Ankpa4–110–94	20^{abcde}	71^{lmnop}	2.8^{CDEFG}	26^{lm}	17.03^{no}	47^{mnopqr}	57.38^{mnopqrstuvw}	19.41^{l}
S19/Ankpa4–11–10	17^{defghij}	60^{CDEFGH}	4.8^{efghi}	23^{wx}	12.03^{yz}	39^{wxyzABC}	18.44$^{k1l1m1n1\circ1p1q1r1s1t1u1v1w1\times1y1z1A1B1C1D1E1}$	8.89$^{k1l1m1n1\circ1p1q1r1s1t1u1v1w1}$
S19/Ankpa4–111–95	17^{defghij}	61^{BCDEFG}	1.7^{NOPQRSTU}	23^{wx}	10.03^{C}	26^{NOPQ}	15.43$^{p1q1r1s1t1u1v1w1\times1y1z1A1B1C1D1E1F1G1H1I1}$	3.74 g$^{2h2i2j2k2l2m2n2\circ2p2}$
S19/Ankpa4–112–96	17^{defghij}	62^{ABCDEF}	2.4^{GHIJK}	24st	10.03^{C}	43rs^{tuvw}	18.91$^{k1l1m1n1\circ1p1q1r1s1t1u1v1w1\times1y1z1A1B1C1D1E1}$	13.94st^{uvwxyz}
S19/Ankpa4–113–97	14^{hijk}	55^{IJKLM}	2.3^{HIJKL}	25^{nopq}	11.03^{AB}	46^{nopqrs}	68.6^{fghijklm}	5.82$^{M1N1\circ1P1Q1R1S1T1U1V1W1\times1Y1}$
S19/Ankpa4–114–98	14^{hijk}	63^{vwzABCD}	3.6^{tuvwx}	24st	12.03^{yz}	43rs^{tuvw}	56.6^{nopqrstuvwxy}	14.32rs^{tuvwx}
S19/Ankpa4–115–99	20^{abcde}	70^{mnopq}	3.2^{xyzABC}	25^{nopq}	16.03^{pqr}	37^{ABCDEFG}	14.91$^{q1r1s1t1u1v1w1\times1y1z1A1B1C1D1E1F1G1H1I1J1}$	5.94$^{M1N1\circ1P1Q1R1S1T1U1V1W1\times1}$
S19/Ankpa4–116–100	17^{defghij}	60^{CDEFGH}	4.8^{efghi}	23^{wx}	7.03^{F}	29^{KLMNO}	30.88$^{\circ PQRSTUVWXYZa1b1c1d1e1f1g1h1i1j1k1}$	10.32^{XYZa1b1c1d1e1f1g1h1i1j1}

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Table 7 (*continued*)

Genotype	DE (days)	DFF (days)	IL (cm)	PH (cm)	PL (cm)	CW (cm)	GY (g plot^{-1})	GYP (g plant^{-1})
S19/Ankpa4–117–101	21^{abcd}	76^{defghijk}	3.5^{uvwxy}	27^{hij}	16.03^{pqr}	43rs^{tuvw}	8.84^{C1D1E1F1G1H1I1J1}	4.88$^{V1W1\times1Y1Z1a2b2c2d2e2f2g2}$
S19/Ankpa4–120–103	20^{abcde}	70^{mnopq}	3.1^{yzABCD}	25^{nopq}	10.03^{C}	54^{efghij}	11.68$^{\times1y1z1A1B1C1D1E1F1G1H1I1J1}$	3.37$^{j2k2l2m2n2\circ2p2q2r2}$
S19/Ankpa4–12–11	22^{ab}	79^{abcde}	1.8^{MNOPQRST}	29^{f}	21.03^{f}	32^{HIJKL}	8.6^{C1D1E1F1G1H1I1J1}	5.32$^{P1Q1R1U1V1W1\times1Y1Z1a2b2c2d2e2f2}$
S19/Ankpa4–122–104	21^{abcd}	77^{cdefghij}	3.5^{uvwxy}	28 g	20.03^{gh}	53^{fghijk}	31.51^{NOPQRSTUVWXYZa1b1c1d1e1f1g1h1i1j1}	10.53^{VWXYZa1b1c1d1e1f1g1}
S19/Ankpa4–123–105	17^{defghij}	63^{vwxzABCD}	2.9^{BCDEF}	24st	10.03^{C}	55^{defgh}	66.91^{fghijklmn}	21.94^{j}
S19/Ankpa4–124–106	20^{abcde}	70^{mnopq}	2.1^{JKLMN}	25^{nopq}	14.03^{v}	48^{lmnopq}	43.44^{zABCDEFGHIJKLMN}	16.07^{pq}
S19/Ankpa4–125–107	22^{ab}	77^{cdefghij}	2.3^{HIJKL}	28 g	19.03^{ij}	36^{BCDEFGH}	14.6$^{r1s1t1u1v1w1\times1y1z1A1B1C1D1E1F1G1H1I1J1}$	5.32$^{P1Q1R1S1U1V1W1\times1Y1Z1a2b2c2d2e2f2}$
S19/Ankpa4–126–108	17^{defghij}	63^{vwxyzABCD}	3.8rs^{tuv}	24st	13.03^{x}	38^{xyzABCD}	47.44^{uvwxyzABCDEFGHI}	10.17^{YZa1b1c1d1e1f1g1h1i1j1}
S19/Ankpa4–127–109	21^{abcd}	56^{HIJKL}	3.4^{vwxyzA}	24st	11.03^{AB}	50^{ijklmn}	25.44$^{Za1b1d1e1f1g1h1i1j1k1l1m1n1\circ1p1q1r1s1t1u1}$	7.37^{y1z1A1B1C1D1E1F1G1H1I1J1}
S19/Ankpa4–128–110	14^{hijk}	54^{JKLMN}	3.1^{yzABCD}	22^{z}	11.03^{AB}	26^{NOPQ}	8.45^{C1D1E1F1G1H1I1J1}	3.77 g$^{2h2i2j2k2l2m2n2\circ2p2}$
S19/Ankpa4–129–111	13^{ijk}	52^{LMNO}	4.7^{fghijkl}	20^{C}	8.03^{E}	34^{DFGHIJ}	13.44$^{u1w1\times1y1z1A1B1C1D1E1F1G1H1I1J1}$	6.07$^{L1M1N1\circ1P1Q1R1S1T1U1V1}$
S19/Ankpa4–130–112	23^{a}	80^{abcd}	1^{Yb1c1d1e1f1g1h1}	28 g	23.03^{c}	27^{MNOPQ}	22.6 g$^{1h1i1j1k1l1m1n1\circ1p1q1r1s1t1u1v1w1\times1y1z1A1}$	12.32^{FGHIJKLMNO}
S19/Ankpa4–131–113	15^{ghijk}	50^{NOPQRS}	5.2^{de}	19^{D}	6.03^{G}	61^{ab}	27.51$^{VWXYZa1b1c1d1e1f1g1h1i1j1k1l1m1n1\circ1p1}$	6.53$^{H1I1J1K1L1M1N1\circ1P1}$
S19/Ankpa4–13–12	21^{abcd}	73^{ijklmn}	3.6^{tuvwx}	27^{hij}	18.03^{kl}	25$^{\circ PQ}$	59.53^{klmnopqrstu}	13.84^{tuvwxyzAB}
S19/Ankpa4–133–114	22^{ab}	78^{bcdef}	2.4^{GHIJK}	29^{f}	20.03^{gh}	25$^{\circ PQ}$	28.91^{RSTUVWXYZa1b1c1d1e1f1g1h1i1j1k1l1m1}	1.94$^{t2u2v2w2\times2}$
S19/Ankpa4–134–115	20^{abcde}	70^{mnopq}	3.4^{vwxyzA}	25^{nopq}	14.03^{v}	49^{klmnop}	63.53^{ijklmnop}	10.44^{VWXYZa1b1c1d1e1f1g1h1i1}
S19/Ankpa4–136–116	17^{defghij}	60^{CDEFGH}	5.1^{def}	23^{wx}	12.03^{yz}	51^{hijklm}	26.6$^{XYZa1b1c1d1e1f1g1h1i1j1k1l1m1n1\circ1p1q1r1s1}$	6.82^{F1G1H1I1J1K1L1M1}
S19/Ankpa4–137–117	17^{defghij}	60^{CDEFGH}	3.8rs^{tuv}	23^{wx}	12.03^{yz}	49^{klmnop}	7.44^{D1E1F1G1H1I1J1}	4.07 g^{2h2i2j2k2l2m2n2}
S19/Ankpa4–138–118	17^{defghij}	60^{CDEFGH}	3.9^{qrstu}	23^{wx}	11.03^{AB}	52^{ghijkl}	27.53$^{VWXYZa1b1c1d1e1f1g1h1i1j1k1l1m1n1\circ1p1}$	10.14^{Za1b1c1d1e1f1g1h1i1j1}
S19/Ankpa4–139–119	19^{abcdefg}	68$^{\circ pqrst}$	1.2^{VWXYZa1b1c1d1e1f1g1}	25^{nopq}	14.03^{v}	56^{cdefg}	29.44^{QRSTUVWXYZa1b1c1d1e1f1g1h1i1j1k1l1}	6.57$^{H1I1J1K1L1M1N1\circ1}$
S19/Ankpa4–140–120	18^{bcdefgh}	65rs^{tuvwxyzAB}	0.7^{h1}	24st	13.03^{x}	63^{a}	31.51^{NOPQRSTUVWXYZa1b1c1d1e1f1g1h1i1j1}	8.53$^{q1r1s1t1u1v1w1\times1y1z1A1}$
S19/Ankpa4–141–121	22^{ab}	79^{abcde}	3.3^{wxyzAB}	28 g	20.03^{gh}	43rs^{tuvw}	48.6^{uvwxyzABCDEFGH}	16.62$^{\circ p}$
S19/Ankpa4–14–13	16^{efghijk}	59^{DEFGHI}	1.4^{TUVWXY}	23^{wx}	11.03^{AB}	44^{qrstuv}	6.91^{E1F1G1H1I1J1}	1.94$^{t2u2v2w2\times2}$
S19/Ankpa4–142–122	14^{hijk}	57^{GHIJK}	4.3^{lmnopq}	22^{z}	10.03^{C}	57^{bcdef}	94.6^{c}	32.02^{b}
S19/Ankpa4–143–123	23^{a}	80^{abcd}	1.6^{QRSTUV}	29^{f}	20.03^{gh}	36^{BCDEFGH}	41.51^{CDEFGHIJKLMNOPQ}	11.23$^{\circ PQRSTUVWXYZa1b1c1}$
S19/Ankpa4–145–124	17^{defghij}	61^{BCDEFG}	3.8rs^{tuv}	23^{wx}	11.03^{AB}	31^{IJKLM}	16.91$^{m1n1\circ1p1q1r1s1t1u1v1w1\times1y1z1A1B1C1D1E1F1G1}$	6.94^{D1E1F1G1H1I1J1K1L1M1}
S19/Ankpa4–146–125	20^{abcde}	70^{mnopq}	3^{ABCDE}	25^{nopq}	15.03st	54^{efghij}	40.6^{EFGHIJKLMNOPQRST}	3.12$^{m2n2\circ2p2q2r2s2}$
S19/Ankpa4–147–126	14^{hijk}	56^{HIJKL}	1.4^{TUVWXY}	22^{z}	10.03^{C}	26^{NOPQ}	12.91$^{w1\times1y1z1A1B1C1D1E1F1G1H1I1J1}$	4.94$^{V1W1\times1Y1Z1a2b2c2d2e2f2g2}$
S19/Ankpa4–148–127	20^{abcde}	70^{mnopq}	2.9^{BCDEF}	25^{nopq}	14.03^{v}	48^{lmnopq}	2.6^{J1}	2.32^{r2s2t2u2v2w2}
S19/Ankpa4–150–128	17^{defghij}	74^{fghijklm}	1.6^{QRSTUV}	27^{hij}	12.03^{yz}	57^{bcdef}	35.51^{IJKLMNOPQRSTUVWXYZa1b1c1d1e1}	9.23$^{j1k1l1m1n1\circ1p1q1r1s1t1u1v1}$
S19/Ankpa4–151–129	13^{ijk}	50^{NOPQRS}	5.1^{def}	19^{D}	6.03^{G}	32^{HIJKL}	70.6^{fghijk}	17.82^{mn}
S19/Ankpa4–15–14	13^{ijk}	50^{NOPQRS}	0.8 g^{1h1}	19^{D}	6.03^{G}	55^{defgh}	13.44$^{u1w1\times1y1z1A1B1C1D1E1F1G1H1I1J1}$	4.37^{b2c2d2e2f2g2h2i2j2k2l2}
S19/Ankpa4–152–130	20^{abcde}	71^{lmnop}	3^{zABCDE}	26^{lm}	12.03^{yz}	56^{cdefg}	30.91$^{\circ PQRSTUVWXYZa1b1c1d1e1f1g1h1i1j1k1}$	9.94^{d1e1f1g1h1i1j1k1l1}
S19/Ankpa4–154–131	15^{ghijk}	56^{HIJKL}	3.9^{qrstu}	22^{z}	9.03^{D}	34^{DEFGHIJ}	24.91$^{a1b1d1e1f1g1h1i1j1k1l1m1n1\circ1p1q1r1s1t1u1v1w1}$	10.94^{PRSTUVWXYZa1b1c1d1e1}
S19/Ankpa4–156–132	16^{efghijk}	58^{FGHIJ}	5.2^{de}	23^{wx}	10.03^{C}	37^{ABCDEFG}	33.51^{KLMNOPQRSTUVWXYZa1b1c1d1e1f1g1h1}	12.53^{DEFGHIJKL}
S19/Ankpa4–157–133	16^{efghijk}	59^{DEFGHI}	4^{pqrst}	22^{yz}	13.03^{x}	48^{lmnopq}	39.15^{FGHIJKLMNOPQRSTUVWX}	11.77^{GHIJKLMNOPQRST}
S19/Ankpa4–158–134	16^{efghijk}	59^{DEFGHI}	4.3^{lmnopq}	24st	12.03^{yz}	44^{qrstuv}	29.51^{QRSTUVWXYZa1b1c1d1e1f1g1h1i1j1k1l1}	8.53$^{q1r1s1t1u1v1w1\times1y1z1A1B1}$
S19/Ankpa4–159–135	13^{ijk}	52^{LMNO}	5^{defg}	20^{C}	8.03^{E}	56^{cdefg}	28.91^{RSTUVWXYZa1b1c1d1e1f1g1h1i1j1k1l1m1}	9.24$^{j1k1l1m1n1\circ1p1q1r1s1t1u1}$
S19/Ankpa4–161–136	20^{abcde}	71^{lmnop}	2.7^{DEFGH}	26^{lm}	15.03st	57^{bcdef}	48.91^{uvwxyzABCDEFGH}	10.34^{XYZa1b1c1d1e1f1g1h1i1j1}
S19/Ankpa4–16–15	20^{abcde}	72^{klmno}	1.6^{QRSTUV}	26^{lm}	15.03st	38^{xyzABCD}	18.91$^{k1l1m1n1\circ1p1q1r1s1t1u1v1w1\times1y1z1A1B1C1D1E1}$	7.94$^{w1\times1y1z1A1B1C1D1E1F1}$
S19/Ankpa4–162–137	14^{hijk}	53^{KLMNO}	0.9^{b1c1d1e1f1g1h1}	19^{D}	7.03^{F}	28^{LMNOP}	42.91^{BCDEFGHIJKLMNOP}	10.94^{PRSTUVWXYZa1b1c1d1e1}
S19/Ankpa4–163–138	20^{abcde}	71^{lmnop}	2.9^{BCDEF}	26^{lm}	15.03st	43rs^{tuvw}	10.6^{z1A1B1C1D1E1F1G1H1I1J1}	4.02 g$^{2h2i2j2k2l2m2n2\circ2}$
S19/Ankpa4–164–139	15^{ghijk}	50^{NOPQRS}	4.9^{defgh}	19^{D}	6.03^{G}	25$^{\circ PQ}$	43.22^{ABCDEFGHIJKLMNO}	12.77^{zBCDEFGH}
S19/Ankpa4–165–140	17^{defghij}	60^{CDEFGH}	1.2^{VWXYZa1b1c1d1e1f1g1}	23^{wx}	12.03^{yz}	37^{ABCDEFG}	33.37^{KLMNOPQRSTUVWXYZa1b1c1d1e1f1g1h1}	13.72^{tuvwxyzABC}
S19/Ankpa4–167–141	17^{defghij}	60^{CDEFGH}	2.3^{HIJKL}	23^{wx}	9.03^{D}	34^{DEFGHIJ}	6.91^{E1F1G1H1I1J1}	1.94$^{t2u2v2w2\times2}$
S19/Ankpa4–170–142	17^{defghij}	61^{BCDEFG}	2.6^{EFGHI}	23^{wx}	12.03^{yz}	44^{qrstuv}	22.6 g$^{1h1i1j1k1l1m1n1\circ1p1q1r1s1t1u1v1w1\times1y1z1A1}$	8.32$^{r1s1t1u1v1w1\times1y1z1A1B1C1}$
S19/Ankpa4–171–143	22^{ab}	80^{abcd}	0.9^{b1c1d1e1f1g1h1}	29^{f}	20.03^{gh}	47^{mnopqr}	33.51^{KLMNOPQRSTUVWXYZa1b1c1d1e1f1g1h1}	9.53$^{f1g1h1i1j1k1l1m1n1\circ1p1q1r1}$
S19/Ankpa4–17–16	20^{abcde}	71^{lmnop}	1.1^{WXYZa1b1c1d1e1f1g1h1}	26^{lm}	15.03st	56^{cdefg}	26.91$^{WXYZa1b1c1d1e1f1g1h1i1j1k1l1m1n1\circ1p1q1r1}$	8.64$^{p1q1r1s1t1u1v1w1\times1}$
S19/Ankpa4–172–144	20^{abcde}	73^{hijklmn}	4.6^{ghijklm}	26^{lm}	17.03^{no}	53^{fghijk}	62.91^{ijklmnop}	7.94$^{w1\times1y1z1A1B1C1D1E1F1}$
S19/Ankpa4–173–145	14^{hijk}	54^{JKLMN}	3.6^{tuvwx}	22^{yz}	8.03^{E}	34^{DEFGHIJ}	27.44$^{VWXYZa1b1c1d1e1f1g1h1i1j1k1l1m1n1\circ1p1}$	10.67ST^{VWXYZa1b1c1d1e1f1}
S19/Ankpa4–175–146	17^{defghij}	61^{BCDEFG}	3.9^{qrstu}	23^{wx}	11.03^{AB}	28^{LMNOP}	30.91$^{\circ PQRSTUVWXYZa1b1c1d1e1f1g1h1i1j1k1}$	9.94^{d1e1f1g1h1i1j1k1l1}
S19/Ankpa4–176–147	16^{efghijk}	59^{DEFGHI}	3.7st^{tuvw}	22^{yz}	11.03^{AB}	43rs^{tuvw}	41^{DEFGHIJKLMNOPQRS}	10.32^{XYZa1b1c1d1e1f1g1h1i1j1}
S19/Ankpa4–177–148	12^{k}	50^{NOPQRS}	3.3^{wxyzAB}	26^{lm}	6.03^{G}	37^{ABCDEFG}	21.53$^{h1i1j1k1l1m1n1\circ1p1q1r1s1t1u1v1w1\times1y1z1A1B1}$	8.68$^{\circ1p1q1r1s1t1u1v1w1}$
S19/Ankpa4–178–149	17^{defghij}	62^{ABCDEF}	3.5^{uvwxy}	24st	12.03^{yz}	36^{BCDEFGH}	15.53$^{p1q1r1s1t1u1v1w1\times1y1z1A1B1C1D1E1F1G1H1I1}$	6.14$^{K1L1M1N1\circ1P1Q1R1S1T1U1}$
S19/Ankpa4–179–150	17^{defghij}	61^{BCDEFG}	3.9^{qrstu}	23^{wx}	12.03^{yz}	38^{xyzABCD}	33.51^{KLMNOPQRSTUVWXYZa1b1c1d1e1f1g1h1}	12.53^{DEFGHIJKLM}

(*continued on next page*)

Table 7 (*continued*)

Genotype	DE (days)	DFF (days)	IL (cm)	PH (cm)	PL (cm)	CW (cm)	GY (g plot^{-1})	GYP (g plant^{-1})
S19/Ankpa4–180–151	20^{abcde}	72^{klmno}	5^{defg}	25^{nopq}	14.03^{v}	$39^{wxyzABC}$	$38.43^{FGHIJKLMNOPQRSTUVWXY}$	$11.33^{LNOPQRSTUVWXYZ}$
S19/Ankpa4–181–152	$19^{abcdefg}$	69^{nopqr}	4.2^{mnopqr}	24st	12.03^{yz}	28^{LMNOP}	$43.44^{zABCDEFGHIJKLMN}$	24.37^{gh}
S19/Ankpa4–18–17	23^{a}	81^{abc}	0.7^{h1}	31^{d}	23.03^{c}	$40^{uvwxyzAB}$	$12.44^{w1\times1y1z1A1B1C1D1E1F1G1H1I1J1}$	$6.37^{I1J1K1L1M1N1\circ1P1Q1R1S1T1U1}$
S19/Ankpa4–182–153	20^{abcde}	$73^{hijklmn}$	2.7^{DEFGH}	26^{lm}	14.03^{v}	$39^{wxyzABC}$	$33.34^{KLMNOPQRSTUVWXYZa1b1c1d1e1f1g1h1}$	$11.11^{PQRSTUVWXYZa1b1c1d1}$
S19/Ankpa4–183–154	$16^{efghijk}$	58^{FGHIJ}	4.1^{nopqrs}	23^{wx}	12.03^{yz}	57^{bcdef}	73.53^{efghi}	17.34^{mno}
S19/Ankpa4–184–155	21^{abcd}	$77^{cdefghij}$	3.9^{qrstu}	28 g	18.03^{kl}	$38^{xyzABCD}$	82.6^{de}	20.82^{k}
S19/Ankpa4–185–156	$16^{efghijk}$	59^{DEFGHI}	3.3^{wxyzAB}	24st	12.03^{yz}	32^{HIJKL}	$18.91^{k1l1m1n1\circ1p1q1r1s1t1u1v1w1\times1y1z1A1B1C1D1E1}$	$7.94^{w1\times1y1z1A1B1C1D1E1F1}$
S19/Ankpa4–186–157	$17^{defghij}$	60^{CDEFGH}	4^{pqrst}	23^{wx}	14.03^{v}	32^{HIJKL}	$47.3^{vwxyzABCDEFGHI}$	$13.56^{vwxyzABCDE}$
S19/Ankpa4–187–158	15^{ghijk}	52^{LMNO}	2.8^{CDEFG}	20^{C}	7.03^{F}	51^{hijklm}	$21.44^{h1i1j1k1l1m1n1\circ1p1q1r1s1t1u1v1w1\times1y1z1A1B1}$	$10.07^{a1b1c1d1e1f1g1h1i1j1}$
S19/Ankpa4–188–159	20^{abcde}	52^{LMNO}	5.3^{cd}	21^{A}	8.03^{E}	58^{bcde}	$19.44^{j1k1l1m1n1\circ1p1q1r1s1t1u1v1w1\times1y1z1A1B1C1D1E1}$	$4.57^{a2b2c2d2e2f2g2h2i2j2}$
S19/Ankpa4–190–160	15.5^{ghijk}	58.5^{FGHI}	4.8^{fghij}	23^{wx}	9.03^{D}	34.5^{DFGHI}	$25.22^{e1f1g1h1i1j1k1l1m1n1\circ1p1q1r1s1t1u1v1}$	$12.04^{GHIJKLMNOPQ}$
S19/Ankpa4–191–161	14^{hijk}	54^{JKLMN}	$4.7^{fghijkl}$	28 g	8.03^{E}	51^{hijklm}	$10.49^{z1A1B1C1D1E1F1G1H1I1J1}$	$2.1^{s2t2u2v2w2}$
S19/Ankpa4–192–162	$17^{defghij}$	53^{KLMNO}	2.2^{IJKLM}	20^{C}	7.03^{F}	59^{abcd}	$23.81^{e1f1g1h1i1j1k1l1m1n1\circ1p1q1r1s1t1u1v1w1\times1}$	$10.47^{VWXYZa1b1c1d1e1f1g1h1i1}$
S19/Ankpa4–193–163	21^{abcd}	$73^{hijklmn}$	2.7^{DEFGH}	23^{wx}	12.03^{yz}	61^{ab}	$9.53^{B1C1D1E1F1G1H1I1J1}$	$4.14\ g^{2h2i2j2k2l2m2n2}$
S19/Ankpa4–194–164	22^{ab}	$77^{cdefghij}$	4.2^{mnopqr}	28 g	15.03st	52^{ghijkl}	$34.91^{JKLMNOPQRSTUVWXYZa1b1c1d1e1f1g1}$	$11.24^{\circ PQRSTUVWXYZa1}$
S19/Ankpa4–195–165	14^{hijk}	56^{HIJKL}	$4.6^{ghijklm}$	22^{yz}	10.03^{C}	$25^{\circ PQ}$	$16.6^{m1n1\circ1p1q1r1s1t1u1v1w1\times1y1z1A1B1C1D1E1F1G1}$	$6.02^{L1M1N1\circ1P1Q1R1S1T1U1V1W1}$
S19/Ankpa4–196–166	12^{k}	50^{NOPQRS}	2.9^{BCDEF}	18^{E}	7.03^{F}	$35^{CDEFGHI}$	$39.51^{FGHIJKLMNOPQRSTUV}$	$12.53^{DEFGHIJKLM}$
S19/Ankpa4–197–167	21^{abcd}	$75^{efghijkl}$	2.4^{GHIJK}	27^{hij}	15.03st	61^{ab}	$27.51^{VWXYZa1b1c1d1e1f1g1h1i1j1k1l1m1n1\circ1p1}$	$6.53^{H1I1J1K1L1M1N1\circ1P1}$
S19/Ankpa4–198–168	21^{abcd}	$74^{fghijklm}$	2.6^{EFGHI}	26^{lm}	16.03^{pqr}	29^{KLMNO}	110.6^{b}	27.82^{d}
S19/Ankpa4–199–169	18.5^{bcdefg}	$66rs^{tuvwxyz}$	4.05^{pqrs}	24.5^{qs}	12.53^{xyz}	$38^{yzABCDE}$	$37^{IJKLMNOPQRSTUVWXYZa1b1c1}$	$11.77^{HIJKLMNOPQRSTU}$
S19/Ankpa4–200–170	15^{ghijk}	56^{HIJKL}	$4.5^{hijklmn}$	20^{C}	11.03^{AB}	$35^{CDEFGHI}$	$45.51^{wxyzABCDEFGHIJK}$	$16.53^{\circ p}$
S19/Ankpa4–20–18	14^{hijk}	54^{JKLMN}	$4.4^{iklmnop}$	25^{nopq}	7.03^{F}	$25^{\circ PQ}$	$37.53^{GHIJKLMNOPQRSTUVWXYZ}$	$8.34^{q1r1s1t1u1v1w1\times1y1z1A1B1C1}$
S19/Ankpa4–202–171	$17^{defghij}$	61^{BCDEFG}	$3.8rs^{tuv}$	$24st^{u}$	12.03^{yz}	32^{HIJKL}	$15.44^{p1q1r1s1t1u1v1w1\times1y1z1A1B1C1D1E1F1G1H1I1}$	$10.37^{WXYZa1b1c1d1e1f1g1h1i1j1}$
S19/Ankpa4–203–172	$18^{bcdefgh}$	$67^{pqrstuvw}$	3.4^{vwxyzA}	23^{wx}	11.03^{AB}	49^{klmnop}	$6.91^{E1F1G1H1I1J1}$	$1.94^{t2u2v2w2\times2y2}$
S19/Ankpa4–204–173	$19^{abcdefg}$	69^{nopqr}	$4.7^{fghijkl}$	25^{nopq}	15.03st	59^{abcd}	$6.91^{E1F1G1H1I1J1}$	$1.94^{t2u2v2w2\times2y2}$
S19/Ankpa4–205–174	13^{jk}	53^{KLMNO}	4.2^{mnopqr}	21^{A}	9.03^{D}	26^{NOPQ}	$29.51^{QRSTUVWXYZa1b1c1d1e1f1g1h1i1j1k1l1}$	$8.53^{q1r1s1t1u1v1w1\times1y1z1A1B1}$
S19/Ankpa4–206–175	22^{ab}	80^{abcd}	$1.5ST^{UVW}$	29^{f}	20.03^{gh}	47^{mnopqr}	$52.91^{pqrstuvwxyzABCD}$	$13.44^{wxyzABCDEF}$
S19/Ankpa4–207–176	$16^{efghijk}$	57^{GHIJK}	4.2^{mnopqr}	22^{yz}	9.03^{D}	32^{HIJKL}	$18.6^{k1l1m1n1\circ1p1q1r1s1t1u1v1w1\times1y1z1A1B1C1D1E1}$	$10.32^{XYZa1b1c1d1e1f1g1h1i1j1}$
S19/Ankpa4–208–177	$16^{efghijk}$	58^{FGHIJ}	4.2^{mnopqr}	23^{wx}	11.03^{AB}	$25^{\circ PQ}$	$41.51^{CDEFGHIJKLMNOPQ}$	$13.53^{vwxyzABCDE}$
S19/Ankpa4–210–178	15^{ghijk}	56^{HIJKL}	4.3^{lmnopq}	22^{yz}	11.03^{AB}	$41^{tuvwxyzA}$	$9.53^{B1C1D1E1F1G1H1I1J1}$	$4.14^{e2g2h2i2j2k2l2m2n2}$
S19/Ankpa4–211–179	13^{jk}	52^{LMNO}	2.6^{EFGHI}	20^{C}	7.03^{F}	$40^{uvwxyzAB}$	$8.91^{C1D1E1F1G1H1I1J1}$	$3.94\ g^{2h2i2j2k2l2m2n2\circ2}$
S19/Ankpa4–21–19	$17^{defghij}$	$63^{vwxyzABCD}$	$3.7st^{uvw}$	25^{nopq}	14.03^{v}	58^{bcde}	$55.44^{nopqrstuvwxyzA}$	$14.87rs^{t}$
S19/Ankpa4–212–180	$19^{abcdefg}$	69^{nopqr}	$4.7^{fghijkl}$	25^{nopq}	14.03^{v}	$41^{tuvwxyzA}$	$42.91^{BCDEFGHIJKLMNOP}$	$13.94st^{uvwxyzA}$
S19/Ankpa4–213–181	20^{abcde}	71^{lmnop}	2.8^{CDEFG}	26^{lm}	12.03^{yz}	$41^{tuvwxyzA}$	$29.51^{QRSTUVWXYZa1b1c1d1e1f1g1h1i1j1k1l1}$	$8.53^{q1r1s1t1u1v1w1\times1y1z1A1B1}$
S19/Ankpa4–215–182	15^{ghijk}	56^{HIJKL}	$1.3^{UVWXYZa1b1c1d1e1f1}$	22^{yz}	10.03^{C}	29^{KLMNO}	$57.53^{mnopqrstuvw}$	$9.24^{j1k1l1m1n1\circ1p1q1r1s1t1u1}$
S19/Ankpa4–216–183	20^{abcde}	80^{abcd}	$0.8\ g^{1h1}$	30^{e}	23.03^{c}	51^{hijklm}	$5.44^{F1G1H1I1J1}$	$3.37^{j2k2l2m2n2\circ2p2q2r2}$
S19/Ankpa4–217–184	$17^{defghij}$	60^{CDEFGH}	3.9^{qrstu}	23^{wx}	12.03^{yz}	$43rs^{tuvw}$	$18.91^{k1l1m1n1\circ1p1q1r1s1t1u1v1w1\times1y1z1A1B1C1D1E1}$	$5.94^{M1N1\circ1P1Q1R1S1T1U1V1W1\times1}$
S19/Ankpa4–219–185	22^{ab}	79^{abcde}	$4.4^{iklmnop}$	25^{nopqr}	17.03^{no}	27^{MNOPQ}	$16.34^{n1\circ1p1q1r1s1t1u1v1w1\times1y1z1A1B1C1D1E1F1G1}$	$6.84^{E1F1G1H1I1J1K1L1M1}$
S19/Ankpa4–220–186	20^{abcde}	71^{lmnop}	3.1^{yzABCD}	26^{lm}	16.03^{pqr}	33^{GHIJK}	$22.81\ g^{1h1i1j1k1l1m1n1\circ1p1q1r1s1t1u1v1w1\times1y1z1A1}$	$10.47^{VWXYZa1b1c1d1e1f1g1h1i1}$
S19/Ankpa4–222–187	22^{ab}	79^{abcde}	5.1^{def}	28 g	15.03st	23^{Q}	$34.6^{KLMNOPQRSTUVWXYZa1b1c1d1e1f1g1}$	$8.82^{l1m1n1\circ1p1q1r1s1t1u1v1w1}$
S19/Ankpa4–223–188	$17^{defghij}$	60^{CDEFGH}	3.2^{xyzABC}	$24st^{u}$	12.03^{yz}	$34^{DEFGHIJ}$	$7.44^{D1E1F1G1H1I1J1}$	$6.37^{I1J1K1L1M1N1\circ1P1Q1R1S1T1U1}$
S19/Ankpa4–224–189	13^{jk}	53^{KLMNO}	2.9^{BCDEF}	27^{hij}	10.03^{C}	$36^{BCDEFGH}$	$44.91^{xyzABCDEFGHIJKLM}$	20.94^{k}
S19/Ankpa4–226–191	$17^{defghij}$	60^{CDEFGH}	$1.7^{NOPQRSTU}$	23^{wx}	11.03^{AB}	56^{cdefg}	$61.53^{jklmnopqrs}$	$14.34rs^{tuvwx}$
S19/Ankpa4–228–192	$16^{efghijk}$	58^{FGHIJ}	4.9^{defgh}	23^{wx}	13.03^{wx}	29^{KLMNO}	$17.53^{l1m1n1\circ1p1q1r1s1t1u1v1w1\times1y1z1A1B1C1D1E1F1}$	$6.84^{E1F1G1H1I1J1K1L1M1}$
S19/Ankpa4–231–191	13^{jk}	51^{MNOP}	4.3^{lmnopq}	20^{C}	8.03^{E}	24^{PQ}	$47.44^{uvwxyzABCDEFGHI}$	$10.17^{YZa1b1c1d1e1f1g1h1i1j1}$
S19/Ankpa4–23–20	20^{abcde}	70^{mnopq}	3.5^{uvwxy}	26^{lm}	16.03^{pqr}	31^{IJKLM}	$15.44^{p1q1r1s1t1u1v1w1\times1y1z1A1B1C1D1E1F1G1H1I1}$	$10.37^{WXYZa1b1c1d1e1f1g1h1i1j1}$
S19/Ankpa4–232–194	$17^{defghij}$	60^{CDEFGH}	4.1^{nopqrs}	23^{wx}	12.03^{yz}	51^{hijklm}	$47.53^{uvwxyzABCDEFGHI}$	$7.24^{C1D1E1F1G1H1I1J1K1L1}$
S19/Ankpa4–232–195	12^{k}	$49^{\circ PQRS}$	5.2^{de}	18^{E}	6.03^{G}	29^{KLMNO}	$23.44^{e1f1g1h1i1j1k1l1m1n1\circ1p1q1r1s1t1u1v1w1\times1}$	$9.37\ g^{1h1i1j1k1l1m1n1\circ1p1q1r1s1}$
S19/Ankpa4–234–196	22^{ab}	79^{abcde}	2.1^{JKLMN}	30^{e}	23.03^{c}	27^{MNOPQ}	$21.53^{h1i1j1k1l1m1n1\circ1p1q1r1s1t1u1v1w1\times1y1z1A1B1}$	$8.14^{t1u1v1w1\times1y1z1A1B1C1}$
S19/Ankpa4–234–197	22^{ab}	79^{abcde}	2.1^{JKLMN}	28 g	20.03^{gh}	31^{IJKLM}	96.6^{c}	19.32^{l}
S19/Ankpa4–235–198	13^{jk}	$63^{vwxyzABCD}$	$1.7^{NOPQRSTU}$	$24st^{u}$	13.03^{wx}	53^{fghijk}	$57.53^{mnopqrstuvw}$	$13.34^{xyzABCDEF}$
S19/Ankpa4–237–200	15^{ghijk}	56^{HIJKL}	$4.4^{iklmnop}$	22^{yz}	8.03^{E}	53^{fghijk}	$31.51^{NOPQRSTUVWXYZa1b1c1d1e1f1g1h1i1j1}$	$10.53^{VWXYZa1b1c1d1e1f1g1h1}$
S19/Ankpa4–238–201	22^{ab}	$77^{cdefghij}$	2.3^{HIJKL}	27^{hij}	18.03^{kl}	29^{KLMNO}	$56.51^{nopqrstuvwxy}$	$14.03st^{uvwxy}$
S19/Ankpa4–239–202	12^{k}	47^{PQS}	5.1^{def}	17^{F}	7.03^{F}	26^{NOPQ}	$31.51^{NOPQRSTUVWXYZa1b1c1d1e1f1g1h1i1j1}$	$8.53^{q1r1s1t1u1v1w1\times1y1z1A1B1}$
S19/Ankpa4–241–203	22^{ab}	78^{bcdef}	$4.6^{ghijklm}$	29^{f}	21.03^{f}	48^{lmnopq}	$62.91^{ijklmnop}$	15.94^{pq}

(*continued on next page*)

Table 7 (*continued*)

Genotype	DE (days)	DFF (days)	IL (cm)	PH (cm)	PL (cm)	CW (cm)	GY (g plot^{-1})	GYP (g plant^{-1})
S19/Ankpa4–242–204	15^{ghijk}	62^{ABCDEF}	2.5^{FGHIJ}	24st^{u}	12.03^{yz}	32^{HIJKL}	49.51st^{uvwxyzABCDEFG}	28.53^{cd}
S19/Ankpa4–243–205	16^{efghijk}	57^{GHIJK}	4.6^{ghijklm}	20^{C}	11.03^{AB}	34^{DEFGHIJ}	3.53^{H1I1J1}	2.14^{s2t2u2v2w2}
S19/Ankpa4–244–206	22^{ab}	79^{abcde}	3.6^{tuvwx}	30^{e}	22.03^{de}	40^{uvwxyzAB}	14.91$^{q1r1s1t1u1v1w1\times1y1z1A1B1C1D1E1F1G1H1I1J1}$	9.94^{d1e1f1g1h1i1j1k1l1m1}
S19/Ankpa4–245–207	14^{hijk}	52^{LMNO}	4.8^{efghijk}	20^{BC}	8.03^{E}	44^{qrstuv}	8.91^{C1D1E1F1G1H1I1J1}	3.94 g$^{2h2i2j2k2l2m2n2\circ2}$
S19/Ankpa4–247–208	17^{defghij}	60^{CDEFGH}	4.2^{mnopqr}	23^{wx}	11.03^{AB}	48^{lmnopq}	25.44$^{Za1b1d1e1f1g1h1i1j1k1l1m1n1\circ1p1q1r1s1t1u1}$	10.07^{a1b1c1d1e1f1g1h1i1j1}
S19/Ankpa4–248–209	17^{defghij}	62^{ABCDEF}	3.8rs^{tuv}	24st^{u}	13.03^{wx}	41^{tuvwxyzA}	28.43$^{TUVWXYZa1b1c1d1e1f1g1h1i1j1k1l1m1n1\circ1}$	11.32^{NOPQRSTUVWXYZ}
S19/Ankpa4–249–210	15^{ghijk}	57^{GHIJK}	4.2^{mnopqr}	23^{wx}	11.03^{AB}	63^{a}	45.44^{wxyzABCDEFGHIJK}	9.77$^{e1f1g1h1i1j1k1l1m1n1\circ1p1}$
S19/Ankpa4–251–211	17^{defghij}	60^{CDEFGH}	5^{defg}	23^{wx}	7.03^{F}	32^{HIJKL}	43.51^{zABCDEFGHIJKLMN}	14.53rs^{tuvw}
S19/Ankpa4–25–21	12^{k}	50^{NOPQRS}	2.4^{GHIJK}	24st^{u}	7.03^{F}	38^{xyzABCDEF}	35.67^{IJKLMNOPQRSTUVWXYZa1b1c1d1e1}	12.47^{EFGHIJKLMN}
S19/Ankpa4–252–212	17^{defghij}	60^{CDEFGH}	4.1^{nopqrs}	24st^{u}	13.03^{wx}	49^{klmnop}	31.82^{NOPQRSTUVWXYZa1b1c1d1e1f1g1h1i1j1}	11.37^{KLMNOPQRSTUVWXY}
S19/Ankpa4–253–213	18^{bcdefgh}	69^{nopqr}	4.1^{nopqrs}	25^{nopqr}	14.03^{v}	46^{nopqrs}	25.53$^{Za1b1d1e1f1g1h1i1j1k1l1m1n1\circ1p1q1r1s1t1u1}$	9.54$^{f1g1h1i1j1k1l1m1n1\circ1p1q1}$
S19/Ankpa4–254–215	22^{ab}	78^{bcdef}	1.1^{WXYZa1b1c1d1e1f1g1h1}	27^{hij}	16.03^{pqr}	26^{NOPQ}	132.6^{a}	26.52^{e}
S19/Ankpa4–255–215	19^{abcdefg}	51^{MNOPQ}	4.9^{defgh}	20^{BC}	8.03^{E}	35^{CDEFGHI}	27.51$^{VWXYZa1b1c1d1e1f1g1h1i1j1k1l1m1n1\circ1p1}$	6.53$^{H1I1J1K1L1M1N1\circ1P1}$
S19/Ankpa4–26–22	20^{abcde}	70^{mnopq}	3.2^{xyzABC}	25^{nopqr}	14.03^{v}	42st^{uvwxy}	37.53^{GHIJKLMNOPQRSTUVWXYZ}	8.34$^{q1r1s1t1u1v1w1\times1y1z1A1B1C1}$
S19/Ankpa4–27–23	15^{ghijk}	55^{IJKLM}	4.5^{hijklmn}	22^{yz}	9.03^{D}	48^{lmnopq}	31.51^{NOPQRSTUVWXYZa1b1c1d1e1f1g1h1i1j1}	8.53$^{q1r1s1t1u1v1w1\times1y1z1A1B1}$
S19/Ankpa4–28–24	21^{abcd}	75^{efghijkl}	2.6^{EFGHI}	26^{lm}	15.03st	48^{lmnopq}	43.53^{zABCDEFGHIJKLMN}	9.84$^{e1f1g1h1i1j1k1l1m1n1\circ1}$
S19/Ankpa4–29–25	19^{abcdefg}	68$^{\circ pqrstu}$	3.2^{xyzABC}	25^{nopqr}	14.03^{v}	56^{cdefg}	47.51^{uvwxyzABCDEFGHI}	16.53$^{\circ p}$
S19/Ankpa4–30–26	13^{jk}	52^{LMNO}	4.8^{efghijk}	20^{BC}	7.03^{F}	45$^{\circ pqrst}$	27.51$^{VWXYZa1b1c1d1e1f1g1h1i1j1k1l1m1n1\circ1p1}$	6.53$^{H1I1J1K1L1M1N1\circ1P1Q1R1}$
S19/Ankpa4–31–27	17^{defghij}	63^{vwxyzABCD}	4^{pqrst}	24st^{u}	10.03^{C}	61^{ab}	48.6^{uvwxyzABCDEFGH}	12.32^{FGHIJKLMNO}
S19/Ankpa4–3–2	21^{abcd}	77^{cdefghij}	1.9^{LMNOPQRS}	27^{hij}	18.03^{kl}	41^{tuvwxyzA}	27.51$^{VWXYZa1b1c1d1e1f1g1h1i1j1k1l1m1n1\circ1p1}$	6.53$^{H1I1J1K1L1M1N1\circ1P1Q1}$
S19/Ankpa4–32–28	22^{ab}	78^{bcdef}	2.2^{IJKLM}	28 g	19.03^{ij}	40^{uvwxyzAB}	23.44$^{e1f1g1h1i1j1k1l1m1n1\circ1p1q1r1s1t1u1v1w1\times1}$	6.87^{E1F1G1H1I1J1K1L1M1}
S19/Ankpa4–33–29	18^{bcdefgh}	66^{qrstuvwxyzA}	0.8 g^{1h1}	23^{wx}	12.03^{yz}	49^{klmnop}	16.91$^{m1n1\circ1p1q1r1s1t1u1v1w1\times1y1z1A1B1C1D1E1F1G1}$	11.94^{GHIJKLMNOPQR}
S19/Ankpa4–339–266	17^{defghij}	68$^{\circ pqrstu}$	1.9^{LMNOPQRS}	23^{wx}	11.03^{AB}	48^{lmnopq}	75.53^{efgh}	17.84^{mn}
S19/Ankpa4–34–30	22^{ab}	78^{bcdefg}	3.7st^{uvw}	28 g	19.03^{ij}	28^{LMNOP}	31.51^{NOPQRSTUVWXYZa1b1c1d1e1f1g1h1i1j1}	10.53^{VWXYZa1b1c1d1e1f1g1h1}
S19/Ankpa4–36–31	23^{a}	83^{a}	0.9^{b1c1d1e1f1g1h1}	34^{a}	26.03^{a}	26^{NOPQ}	38.91^{FGHIJKLMNOPQRSTUVWX}	12.64^{CDEFGHI}
S19/Ankpa4–37–32	13^{jk}	63^{vwxyzABCD}	2^{KLMNOPQR}	24st^{u}	18.03^{kl}	48^{lmnopq}	41.33^{CDEFGHIJKLMNOPQR}	9.87^{e1f1g1h1i1j1k1l1m1n1}
S19/Ankpa4–38–33	18^{bcdefgh}	65rs^{tuvwxyzAB}	3.6^{tuvwx}	24st^{u}	12.03^{yz}	25$^{\circ PQ}$	37.31^{GHIJKLMNOPQRSTUVWXYZa1}	11.43^{JKLMNOPQRSTUVWX}
S19/Ankpa4–39–34	14^{hijk}	54^{JKLMN}	3.2^{xyzABC}	21^{A}	9.03^{D}	49^{klmnop}	18.54$^{k1l1m1n1\circ1p1q1r1s1t1u1v1w1\times1y1z1A1B1C1D1E1}$	3.32$^{k2l2m2n2\circ2p2q2r2}$
S19/Ankpa4–40–35	22^{ab}	79^{abcde}	3.5^{uvwxy}	23^{wx}	19.03^{ij}	32^{HIJKL}	70.91^{fghijk}	14.74rs^{tu}
S19/Ankpa4–42–36	17^{defghij}	62^{ABCDEF}	3.1^{yzABCD}	24st^{u}	12.03^{yz}	48^{lmnopq}	29.44^{QRSTUVWXYZa1b1c1d1e1f1g1h1i1j1k1l1}	6.57$^{H1I1J1K1L1M1N1\circ1}$
S19/Ankpa4–43–37	14^{hijk}	55^{IJKLM}	4.7^{fghijkl}	27^{hij}	8.03^{E}	50^{ijklmn}	43.5^{zABCDEFGHIJKLMN}	12.55^{DEFGHIJK}
S19/Ankpa4–44–38	13^{jk}	52^{LMNO}	2.1^{JKLMN}	20^{BC}	8.03^{E}	53^{fghijk}	45.44^{wxyzABCDEFGHIJK}	12.87^{yzABCDEFG}
S19/Ankpa4–46–39	13^{jk}	51^{MNOPQR}	4.7^{fghijkl}	20^{BC}	8.03^{E}	42st^{uvwxy}	27.51$^{VWXYZa1b1c1d1e1f1g1h1i1j1k1l1m1n1\circ1p1}$	6.53$^{H1I1J1K1L1M1N1\circ1P1Q1R1S1}$
S19/Ankpa4–47–40	17^{defghij}	62^{ABCDEF}	4.5^{hijklmn}	23^{wx}	12.03^{yz}	28^{LMNOP}	33.44^{KLMNOPQRSTUVWXYZa1b1c1d1e1f1g1h1}	19.37^{l}
S19/Ankpa4–48–41	20^{abcde}	73^{hijklmn}	5.1^{def}	27^{hij}	18.03^{kl}	35^{CDEFGHI}	29.44^{QRSTUVWXYZa1b1c1d1e1f1g1h1i1j1k1l1}	17.37^{mno}
S19/Ankpa4–49–42	20^{abcde}	70^{mnopq}	3.3^{wxyzAB}	25^{nopqr}	14.03^{v}	43rs^{tuvw}	17.53$^{l1m1n1\circ1p1q1r1s1t1u1v1w1\times1y1z1A1B1C1D1E1F1}$	3.34$^{k2l2m2n2\circ2p2q2r2}$
S19/Ankpa4–50–43	20^{abcde}	74^{fghijklm}	1.1^{WXYZa1b1c1d1e1f1g1h1}	25^{nopqr}	14.03^{v}	53^{fghijk}	91.53^{cd}	16.04^{pq}
S19/Ankpa4–51–44	20^{abcde}	73^{hijklmn}	2.8^{CDEFG}	27^{hij}	17.03^{mno}	49^{klmnop}	44.91^{xyzABCDEFGHIJKLM}	14.64rs^{tuv}
S19/Ankpa4–52–45	21^{abcd}	75^{efghijkl}	1.7^{NOPQRSTU}	26^{lm}	13.03^{wx}	41^{tuvwxyzA}	33^{LMNOPQRSTUVWXYZa1b1c1d1e1f1g1h1}	17.5^{mno}
S19/Ankpa4–53–46	17^{defghij}	62^{ABCDEF}	3.9^{qrstu}	24st^{u}	11.03^{AB}	38^{xyzABCDEF}	31.51^{NOPQRSTUVWXYZa1b1c1d1e1f1g1h1i1j1}	10.53^{VWXYZa1b1c1d1e1f1g1h1}
S19/Ankpa4–5–4	18^{bcdefgh}	65rs^{tuvwxyzAB}	3.4^{vwxyzA}	24st^{u}	13.03^{wx}	54^{efghij}	43.44^{zABCDEFGHIJKLMN}	16.07^{pq}
S19/Ankpa4–55–47	13^{jk}	52^{LMNO}	1.4^{TUVWXYZ}	20^{BC}	7.03^{F}	52^{ghijkl}	33.51^{KLMNOPQRSTUVWXYZa1b1c1d1e1f1g1h1}	12.53^{DEFGHIJKLM}
S19/Ankpa4–56–48	16^{efghijk}	59^{DEFGHI}	4.1^{nopqrs}	23^{wx}	11.03^{AB}	51^{hijklm}	29.51^{QRSTUVWXYZa1b1c1d1e1f1g1h1i1j1k1l1}	8.53$^{q1r1s1t1u1v1w1\times1y1z1A1B1}$
S19/Ankpa4–57–49	21^{abcd}	74^{fghijklm}	1.6^{QRSTUV}	26^{lm}	15.03st^{u}	41^{tuvwxyzA}	57.44^{mnopqrstuvw}	15.37^{qr}
S19/Ankpa4–58–50	20^{abcde}	71^{lmnop}	2.8^{CDEFG}	26^{lm}	16.03^{pqr}	45$^{\circ pqrst}$	27.51$^{UVWXYZa1b1c1d1e1f1g1h1i1j1k1l1m1n1\circ1p1}$	6.53$^{H1I1J1K1L1M1N1\circ1P1Q1R1S1T1}$
S19/Ankpa4–60–51	18^{bcdefgh}	67^{pqrstuvwx}	0.7^{h1}	24st^{u}	13.03^{wx}	32^{HIJKL}	31.53^{NOPQRSTUVWXYZa1b1c1d1e1f1g1h1i1j1}	6.84^{E1F1G1H1I1J1K1L1M1}
S19/Ankpa4–61–52	16^{efghijk}	59^{DEFGHI}	4.6^{ghijklm}	23^{wx}	11.03^{AB}	61^{ab}	59.51^{klmnopqrstu}	12.93^{yzABCDEFG}
S19/Ankpa4–62–53	20^{abcde}	74^{fghijklm}	2.6^{EFGHI}	27^{hij}	11.03^{AB}	49^{klmnop}	25.99$^{YZa1b1d1e1f1g1h1i1j1k1l1m1n1\circ1p1q1r1s1t1}$	5.73$^{M1N1\circ1P1Q1R1S1T1U1V1W1\times1Y1Z1a2}$
S19/Ankpa4–63–54	15^{ghijk}	56^{HIJKL}	1.5ST^{UVWX}	22^{yz}	7.03^{F}	32^{HIJKL}	37.51^{GHIJKLMNOPQRSTUVWXYZ}	16.53$^{\circ p}$
S19/Ankpa4–64–55	17^{defghij}	61^{BCDEFG}	3.8rs^{tuv}	23^{wx}	11.03^{AB}	47^{mnopqr}	33.44^{KLMNOPQRSTUVWXYZa1b1c1d1e1f1g1h1}	9.37 g$^{1h1i1j1k1l1m1n1\circ1p1q1r1s1}$
S19/Ankpa4–6–5	16^{efghijk}	59^{DEFGHI}	4.1^{nopqrs}	23^{wx}	10.03^{C}	34^{DEFGHIJ}	31.51^{NOPQRSTUVWXYZa1b1c1d1e1f1g1h1i1j1}	10.53^{VWXYZa1b1c1d1e1f1g1h1}
S19/Ankpa4–65–56	22^{ab}	79^{abcde}	5.1^{def}	29^{f}	20.03^{gh}	26^{NOPQ}	53.44$^{\circ pqrstuvwxyzABC}$	29.37^{c}
S19/Ankpa4–66–57	21^{abcd}	78^{bcdefg}	2.2^{IJKLM}	29^{f}	21.03^{f}	41^{tuvwxyzA}	39.51^{FGHIJKLMNOPQRSTUV}	12.53^{DEFGHIJKLM}
S19/Ankpa4–67–58	21^{abcd}	74^{fghijklm}	4.2^{mnopqr}	27^{hij}	18.03^{kl}	60^{abc}	13.53$^{t1u1w1\times1y1z1A1B1C1D1E1F1G1H1I1J1}$	5.54$^{N1\circ1P1Q1R1S1T1U1V1W1\times1Y1Z1a2b2}$
S19/Ankpa4–68–59	16^{efghijk}	59^{DEFGHI}	4.1^{nopqrs}	23^{wx}	8.03^{E}	44^{qrstuv}	15.88$^{p1q1r1s1t1u1v1w1\times1y1z1A1B1C1D1E1F1G1H1I1}$	3.98 g$^{2h2i2j2k2l2m2n2\circ2}$

(*continued on next page*)

Table 7 (*continued*)

Genotype	DE (days)	DFF (days)	IL (cm)	PH (cm)	PL (cm)	CW (cm)	GY (g plot^{-1})	GYP (g plant^{-1})
S19/Ankpa4–69–60	22^{ab}	80^{abcd}	2.4^{GHIJK}	30^{e}	23.03^{c}	25$^{\circ PQ}$	76.91^{ef}	25.24^{fg}
S19/Ankpa4–70–61	20^{abcde}	70^{mnopq}	2.8^{CDEFG}	25^{nopqr}	14.03^{v}	41^{tuvwxyzA}	12.6$^{w1\times1y1z1A1B1C1D1E1F1G1H1I1J1}$	4.62^{Z1a2b2c2d2e2f2g2h2i2}
S19/Ankpa4–72–63	15^{ghijk}	57^{GHIJK}	2.3^{HIJKL}	23^{wx}	11.03^{AB}	36^{BCDEFGH}	29.53^{QRSTUVWXYZa1b1c1d1e1f1g1h1i1j1k1l1}	6.34$^{I1J1K1L1M1N1\circ1P1Q1R1S1T1U1}$
S19/Ankpa4–73–64	20^{abcde}	72^{klmno}	2.4^{GHIJK}	26^{lm}	15.03st^{u}	44^{qrstuv}	37.53^{GHIJKLMNOPQRSTUVWXYZ}	13.54^{vwxyzABCDE}
S19/Ankpa4–74–65	23^{a}	81^{abc}	0.9^{b1c1d1e1f1g1h1}	30^{e}	23.03^{c}	30^{JKLMN}	41.51^{CDEFGHIJKLMNOPQ}	13.53^{vwxyzABCDE}
S19/Ankpa4–7–6	16^{efghijk}	58^{FGHIJ}	1.9^{LMNOPQRS}	23^{wx}	10.03^{C}	56^{cdefg}	12.47$^{w1\times1y1z1A1B1C1D1E1F1G1H1I1J1}$	4.35^{c2d2e2f2g2h2i2j2k2l2}
S19/Ankpa4–76–66	13^{jk}	52^{LMNO}	1.1^{WXYZa1b1c1d1e1f1g1h1}	21^{A}	7.03^{F}	58^{bcde}	16.39$^{n1\circ1p1q1r1s1t1u1v1w1\times1y1z1A1B1C1D1E1F1G1}$	3.75 g$^{2h2i2j2k2l2m2n2\circ2p2}$
S19/Ankpa4–77–67	14^{hijk}	54^{JKLMN}	5.6^{a}	21^{A}	7.03^{F}	43rs^{tuvw}	11.78$^{\times1y1z1A1B1C1D1E1F1G1H1I1J1}$	3.89 g$^{2h2i2j2k2l2m2n2\circ2}$
S19/Ankpa4–79–62	16^{efghijk}	59^{DEFGHI}	4.1^{nopqrs}	23^{wx}	11.03^{AB}	43rs^{tuvw}	31.51^{NOPQRSTUVWXYZa1b1c1d1e1f1g1h1i1j1}	10.53^{VWXYZa1b1c1d1e1f1g1h1}
S19/Ankpa4–79–68	23^{a}	81^{abc}	1.9^{LMNOPQRS}	31^{d}	24.03^{b}	49^{klmnop}	5.44^{F1G1H1I1J1}	3.37$^{j2k2l2m2n2\circ2p2q2r2}$
S19/Ankpa4–81–69	17^{defghij}	60^{CDEFGH}	3.6^{tuvwx}	23^{wx}	11.03^{AB}	58^{bcde}	18.91$^{k1l1m1n1\circ1p1q1r1s1t1u1v1w1\times1y1z1A1B1C1D1E1}$	5.94$^{M1N1\circ1P1Q1R1S1T1U1V1W1\times1}$
S19/Ankpa4–82–70	22^{ab}	79^{abcde}	4.2^{mnopqr}	30^{e}	10.03^{C}	40^{uvwxyzAB}	26.91$^{WXYZa1b1c1d1e1f1g1h1i1j1k1l1m1n1\circ1p1q1r1}$	11.94^{GHIJKLMNOPQR}
S19/Ankpa4–83–71	15^{ghijk}	57^{GHIJK}	2.7^{DEFGH}	22^{yz}	10.03^{C}	56^{cdefg}	29.51^{QRSTUVWXYZa1b1c1d1e1f1g1h1i1j1k1l1}	8.53$^{q1r1s1t1u1v1w1\times1y1z1A1B1}$
S19/Ankpa4–84–72	15^{ghijk}	57^{GHIJK}	4.3^{lmnopq}	23^{wx}	12.03^{yz}	25$^{\circ PQ}$	21.52$^{h1i1j1k1l1m1n1\circ1p1q1r1s1t1u1v1w1\times1y1z1A1B1}$	8.77$^{l1n1\circ1p1q1r1s1t1u1v1w1}$
S19/Ankpa4–85–73	22^{ab}	79^{abcde}	2.9^{BCDEF}	29^{f}	21.03^{f}	34^{DEFGHIJ}	15.37$^{p1q1r1s1t1u1v1w1\times1y1z1A1B1C1D1E1F1G1H1I1}$	5.37$^{\circ1P1Q1R1S1T1U1V1W1\times1Y1Z1a2b2c2d2}$
S19/Ankpa4–86–74	15^{ghijk}	56^{HIJKL}	2.1^{JKLMNO}	21^{A}	15.03st^{u}	56^{cdefg}	39.44^{FGHIJKLMNOPQRSTUVW}	8.57$^{q1r1s1t1u1v1w1\times1y1}$
S19/Ankpa4–8–7	20^{abcde}	71^{lmnop}	2.8^{CDEFG}	26^{lm}	15.03st^{u}	35^{CDEFGHI}	66.6^{fghijklmn}	16.83^{nop}
S19/Ankpa4–88–75	15^{ghijk}	57^{GHIJK}	4.2^{mnopqr}	22^{yz}	10.03^{C}	48^{lmnopq}	25.44$^{Za1b1d1e1f1g1h1i1j1k1l1m1n1\circ1p1q1r1s1t1u1}$	5.77$^{M1N1\circ1P1Q1R1S1T1U1V1W1\times1Y1Z1}$
S19/Ankpa4–89–102	18^{bcdefgh}	77^{cdefghij}	0.3^{i1}	27^{hij}	17.03^{mno}	48^{lmnopq}	44.6^{yzABCDEFGHIJKLM}	2.02^{s2t2u2v2w2}
S19/Ankpa4–89–76	20^{abcde}	70^{mnopq}	1.4^{TUVWXYZa1}	25^{nopqr}	14.03^{v}	59^{abcd}	54.6$^{\circ pqrstuvwxyzAB}$	10.92^{PRSTUVWXYZa1b1c1d1e1}
S19/Ankpa4–90–77	20^{abcde}	71^{lmnop}	3^{zABCDE}	26^{lm}	16.03^{pqr}	41^{tuvwxyzA}	69.44^{fghijkl}	4.07 g^{2h2i2j2k2l2m2n2}
S19/Ankpa4–91–78	20^{abcde}	71^{lmnop}	2.9^{BCDEF}	26^{lm}	15.03st^{u}	43rs^{tuvw}	53.51$^{\circ pqrstuvwxyzABC}$	19.53^{l}
S19/Ankpa4–92–79	19^{abcdefg}	69^{nopqr}	4.2^{mnopqr}	25^{nopqr}	15.03st^{u}	25$^{\circ PQ}$	50.6^{qrstuvwxyzABCDEF}	17.32^{mno}
S19/Ankpa4–93–80	22^{ab}	79^{abcde}	1^{YZb1c1d1e1f1g1h1}	30^{e}	22.03^{de}	27^{MNOPQ}	48.6^{uvwxyzABCDEFGH}	16.62$^{\circ p}$
S19/Ankpa4–94–81	23^{a}	82^{ab}	3.9^{qrstu}	32^{c}	23.03^{c}	49^{klmnop}	55.44^{nopqrstuvwxyzA}	14.87rs^{t}
S19/Ankpa4–95–82	20^{abcde}	52^{LMNO}	1.9^{LMNOPQRS}	20^{BC}	7.03^{F}	25$^{\circ PQ}$	6.91^{E1F1G1H1I1J1}	1.94$^{s2t2u2v2w2\times2y2}$
S19/Ankpa4–96–83	18^{bcdefgh}	67^{pqrstuvwxy}	1.4^{TUVWXYZa1}	23^{wx}	11.03^{AB}	40^{uvwxyzAB}	13.53$^{t1u1w1\times1y1z1A1B1C1D1E1F1G1H1I1J1}$	11.84^{GHIJKLMNOPQRS}
S19/Ankpa4–96–84	14^{hijk}	56^{HIJKL}	4.3^{lmnopq}	22^{yz}	10.03^{C}	57^{bcdef}	29.44^{QRSTUVWXYZa1b1c1d1e1f1g1h1i1j1k1l1}	11.37^{JKLMNOPQRSTUVWXY}
S19/Ankpa4–97–85	15^{ghijk}	71^{lmnop}	2.8^{CDEFG}	26^{lm}	15.03st^{u}	24^{PQ}	29.51^{QRSTUVWXYZa1b1c1d1e1f1g1h1i1j1k1l1}	8.53$^{q1r1s1t1u1v1w1\times1y1z1A1B1}$
S19/Ankpa4–9–8	15^{ghijk}	55^{IJKLM}	4.5^{hijklmn}	21^{A}	7.03^{F}	57^{bcdef}	6.91^{E1F1G1H1I1J1}	1.94$^{t2u2v2w2\times2y2}$
S19/Ankpa4–98–86	21^{abcd}	78^{bcdefg}	3.5^{uvwxy}	22^{yz}	19.03^{ij}	41^{tuvwxyzA}	17.77$^{l1m1n1\circ1p1q1r1s1t1u1v1w1\times1y1z1A1B1C1D1E1F1}$	3.47$^{i2j2k2l2m2n2\circ2p2q2r2}$
S19/Anpa4–109–90	12^{k}	49$^{\circ PQRS}$	1.8^{MNOPQRST}	22^{yz}	10.03^{C}	25$^{\circ PQ}$	6.91^{E1F1G1H1I1J1}	1.94$^{s2t2u2v2w2\times2y2}$
SONGKHLA	15.6^{fghijk}	56.8^{GHIJK}	4.46^{ijklmno}	23.2^{wx}	9.63^{CD}	38^{xyzABCDEF}	48.4^{uvwxyzABCDEFGH}	11.56^{IJKLMNOPQRSTUVW}
TIGD	14^{hijk}	53.8^{JKLMN}	3.24^{xyzAB}	20.6^{AB}	8.03^{E}	49.2^{klmnop}	14.8$^{q1r1s1t1u1v1w1\times1y1z1A1B1C1D1E1F1G1H1I1J1}$	6.54$^{H1I1J1K1L1M1N1\circ1P1}$
UKZN1	15^{ghijk}	57^{GHIJK}	3.72st^{uv}	23.4^{tvw}	11.03^{AB}	44.6^{pqrstu}	14.4$^{s1t1u1w1\times1y1z1A1B1C1D1E1F1G1H1I1J1}$	4.8$^{\times1Y1Z1a2b2c2d2e2f2g2h2}$
UNISWA	21^{abcd}	72.8^{iklmn}	2.02^{KLMNOP}	26.8^{hijk}	17.43^{lmn}	46.8^{mnopqr}	52.8^{pqrstuvwxyzABCDE}	17.3^{mno}
p-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

⁎**DE**: days to emergence.

DFF: days to 50% flowering.

IL: internode length.

pH: plant height.

PL: petiole length.

CW: canopy width.

GY: grain yield.

GYP: grain yield per plot *Different upper-case letters within a column indicate significant difference among genotypes. **Green-bolded** figures represent highest and **red-bolded** represent lowest values of each parameter in a column.

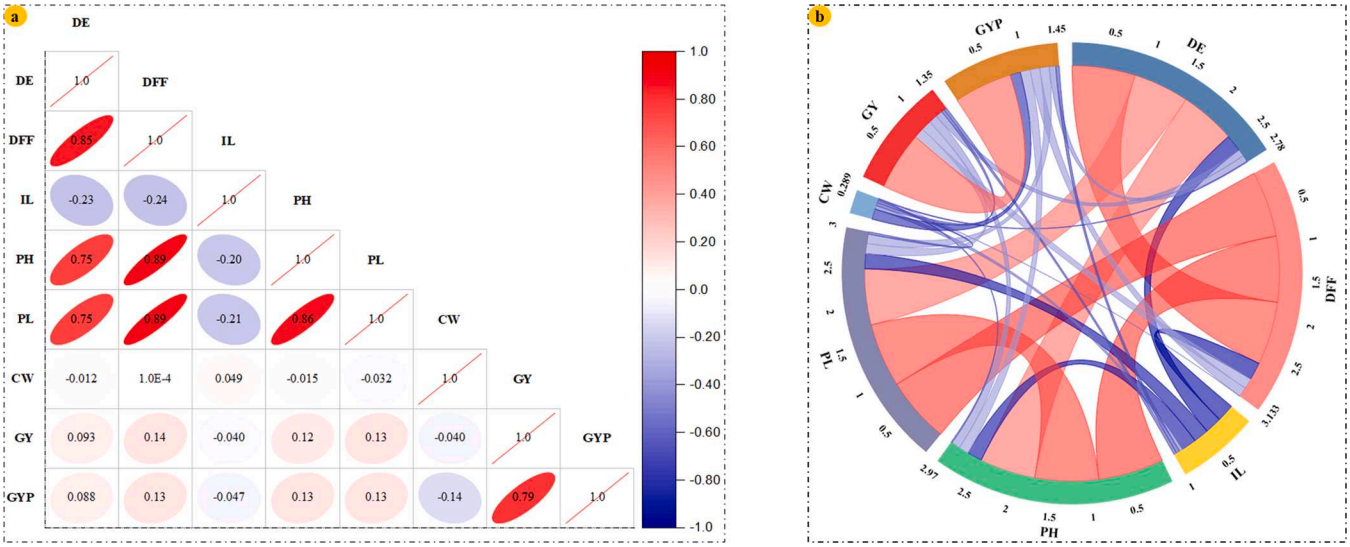

Fig. 2. (a) Pearson correlation matrix and (b) circular chord diagram for BGN agronomic traits in the studied population. DE: days to emergence, DFF: days to 50 % flowering, IL: internode length, pH: plant height, PL: petiole length, CW: canopy width, GY: grain yield, GYP: grain yield per plot.

Principal component analysis (PCA)

Table 8 shows the PCA with factor loadings, eigenvalues, and percent variance for the evaluated traits. PC1 accounted for 45.5 % of the total variation and was positively correlated with DE, DFF, pH and PL. PC2 positively correlated with GY and GYP, contributing to 21.8 % of the total variation. PC3 accounted for 12.6 % of the total variation and was positively correlated with CW. Internode length was positively correlated with PC4, which accounted for 11.3 % of the total variation.

The PC biplots based on PCA analysis were used to picture the relationship among BGN genotypes based on evaluated traits (Fig. 3). Traits represented by parallel vectors or close to each other revealed a strong positive association, and those located nearly opposite (at 180°) showed a highly negative association. In contrast, the vectors toward the sides expressed a weak relationship. The following genotypes—S19/Ankpa4–239–202, S19/Ankpa4–232–195, S19/Ankpa4–151–129, 100SB16ANAM-C, S19/Ankpa4–100–87, IITA686/LunT-312–247, S19/Ankpa4–113–97, and S19/Ankpa4–43–37—are categorized based on high IL. Similarly, IITA686/LunT-403–315, S19, S19/Ankpa4–8–7, S19/Ankpa4–13–12, S19/Ankpa4–93–80, GHC37105, S19/Ankpa4–206–175, S19/Ankpa4–52–45, and IITA686/LunT-437–339 are grouped based on high GY and GYP (Fig. 3).S19/Ankpa4–130–112, S19/Ankpa4–79–68, IITA686/LunT-354–276, IITA686/LunT-407–317, IITA686/LunT-429–332 and IITA686/LunT-366–285 were grouped on high DE, DFF and pH. BURKINA, IITA686/LunT-318–251, IITA686/LunT-269–225, IITA686/LunT-420–325, IITA686/LunT-364–283, S19/Ankpa4–217–184, S19/Ankpa4–223–188, S19/Ankpa4–81–69, S19/Ankpa4–217–184 and S19/Ankpa4–14–13 were grouped based on high CW (Fig. 3).

Agglomerative hierarchical clustering (AHC)

The accessions were classified into four groups based on agronomic traits (GY, GYP and DFF) (Fig. 4). Group A (high-yielding) comprised of 19 genotypes including; IITA686/LunT-419–324, S19/Ankpa4–339–266, IITA686/LunT-348–271, S19/Ankpa4–50–43, S19/Ankpa4–234–197, PONG-BR, S19/Ankpa4–1–1 and S19/Ankpa4–151–129 (Fig. 4a).

Group B (moderately high yielding) comprised of 100 genotypes, including IITA686, S19/Ankpa4–63–54, S19/Ankpa4–180–151, S19/Ankpa4–26–22, S19/Ankpa4–13–12, S19/Ankpa4–224–189, IITA686/LunT-326–257, IITA686/LunT-261–220, IITA686/LunT-312–247, UNI-SWA, S19 and IITA686/LunT-403–315 (Fig. 4b).

In Fig. 4c, 114 genotypes, including IITA686/LunT-411–319, IITA686/LunT-357–278, IITA686/LunT-269–225, IITA686/LunT-397–309, IITA686/LunT-335–263, S19/Ankpa4–48–41, S19/Ankpa4–52–45, S19/Ankpa4–156–132, S19/Ankpa4–25–21, S19/Ankpa4–194–164, EXSOCOTO, DOD R and DIP-C were classified as moderate-yielding genotypes (Group C).

Group D (low-yielding) comprised of 132 genotypes including S19/Ankpa4–128–110, S19/Ankpa4–211–179, S19/Ankpa4–210–178, S19/Ankpa4–12–11, S19/Ankpa4–129–111, S19/Ankpa4–77–67, S19/

Table 8
Summary of factor loadings, eigenvalue, percent and cumulative variation for agronomic traits assessed among 365 BGN genotypes under field conditions.

Trait	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8
DE	0.463	−0.112	0.018	0.045	0.820	0.069	−0.005	0.306
DFF	0.504	−0.090	0.048	0.056	0.020	−0.022	0.015	−0.855
IL	−0.164	0.019	0.457	0.873	0.042	0.003	0.004	−0.016
pH	0.485	−0.087	0.045	0.098	−0.407	0.083	−0.704	0.279
PL	0.486	−0.083	0.028	0.100	−0.392	−0.124	0.694	0.308
CW	−0.023	−0.159	0.871	−0.455	−0.018	0.086	0.024	0.020
GY	0.131	0.680	0.161	−0.074	0.067	−0.688	−0.103	0.027
GYP	0.131	0.690	0.048	−0.017	−0.034	0.701	0.103	−0.011
Eigenvalue	3.638	1.740	1.008	0.906	0.281	0.210	0.137	0.079
Variability (%)	45.479	21.755	12.605	11.326	3.512	2.624	1.711	0.989
Cumulative (%)	45.479	67.234	79.839	91.165	94.677	97.300	99.011	100

DE: days to emergence, DFF: days to 50 % flowering, IL: internode length, pH: plant height, PL: petiole length, CW: canopy width, GY: grain yield, GYP: grain yield per plot.

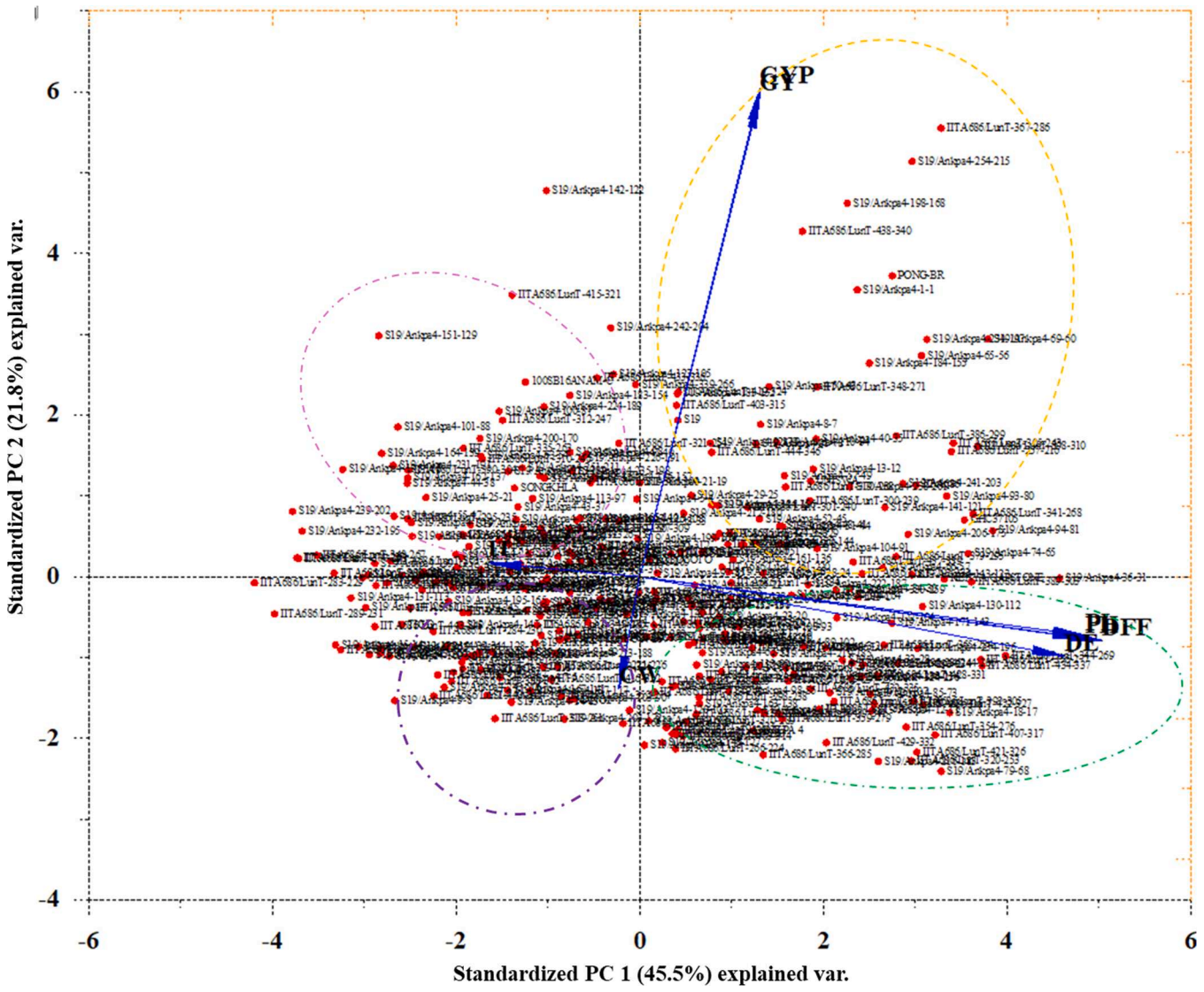

Fig. 3. Principal component (PC) biplot of PC 1 vs PC 2 demonstrating the relationships among agronomic traits for 365 Bambara groundnut genotypes. DE: days to emergence, DFF: days to 50 % flowering, IL: internode length, pH: plant height, PL: petiole length, CW: canopy width, GY: grain yield, GYP: grain yield per plot.

Ankpa4–191–161, ANKPA 4, PONG-CR, 20ACC118CIVB, IITA686/LunT-345–270, IITA686/LunT-402–313, IITA686/LunT-369–287, IITA686/LunT-322–255 and IITA686/LunT-404–316 (Fig. 4d).

Discussion

A plant's growth habit is a crucial agronomic trait that significantly influences its competitive ability, adaptability, and ease of cultivation (Garnier and Navas, 2012; Wang et al., 2006). This study classified vegetative growth habits as bunch, semi-bunch, and spreading. The bunch type was the most predominant (58.5 %), followed by spreading (22.6 %), consistent with findings by Gbaguidi et al. (2018), who reported 40.4 % of BGN landraces exhibiting a bunch growth habit. The predominance of the bunch type can be attributed to its agronomic advantages, particularly for smallholder farmers. This growth habit facilitates manual harvesting by efficiently uprooting plants with minimal pod loss (Ntundu et al., 2006). Selecting the bunch type for breeding programs can improve harvest efficiency and reduce labour costs, especially in low-mechanization farming systems. Promoting this trait through targeted breeding can enhance the crop's attractiveness to farmers, thereby supporting the wider adoption of improved genotypes.

Variations in leaf shape can influence light interception, water-use efficiency, and thermal regulation, ultimately impacting adaptability and yield potential (Gratani, 2014). In this study, oval terminal leaf shapes were most common (40.1 %), followed by round (32.8 %), elliptic (23.7 %), and lanceolate (3.3 %), echoing findings by Ntundu et al. (2006). Broadleaf forms (oval, round, elliptic) enhance photosynthetic capacity through greater light interception and improved PPFD absorption (Karabourniotis et al., 2021; Mandizvo et al., 2022), which can translate to improved biomass accumulation and yield in favourable environments. Conversely, narrower leaves may confer advantages under water-limited conditions by reducing transpiration (Chaves et al., 2016). Breeders can leverage this variation to develop ideotypes tailored to specific environments: broadleaf genotypes for high-input or irrigated systems aiming for maximum yield and narrow-leaf genotypes for rainfed, drought-prone regions where water-use efficiency is critical. This targeted selection would allow farmers to adopt varieties suited to their local agroecologies.

Significant positive correlations were observed (Fig. 2a) between days to emergence (DE) and days to 50 % flowering (DFF) ($r = 0.85$, $p = 0.017$), indicating that early-emerging plants tend to flower earlier (Bitocchi et al., 2017). Additionally, DE showed positive relationships with plant height (pH) ($r = 0.75$, $p = 0.021$) and petiole length (PL) ($r = 0.75$, $p = 0.027$), suggesting that early emergence promotes vigorous

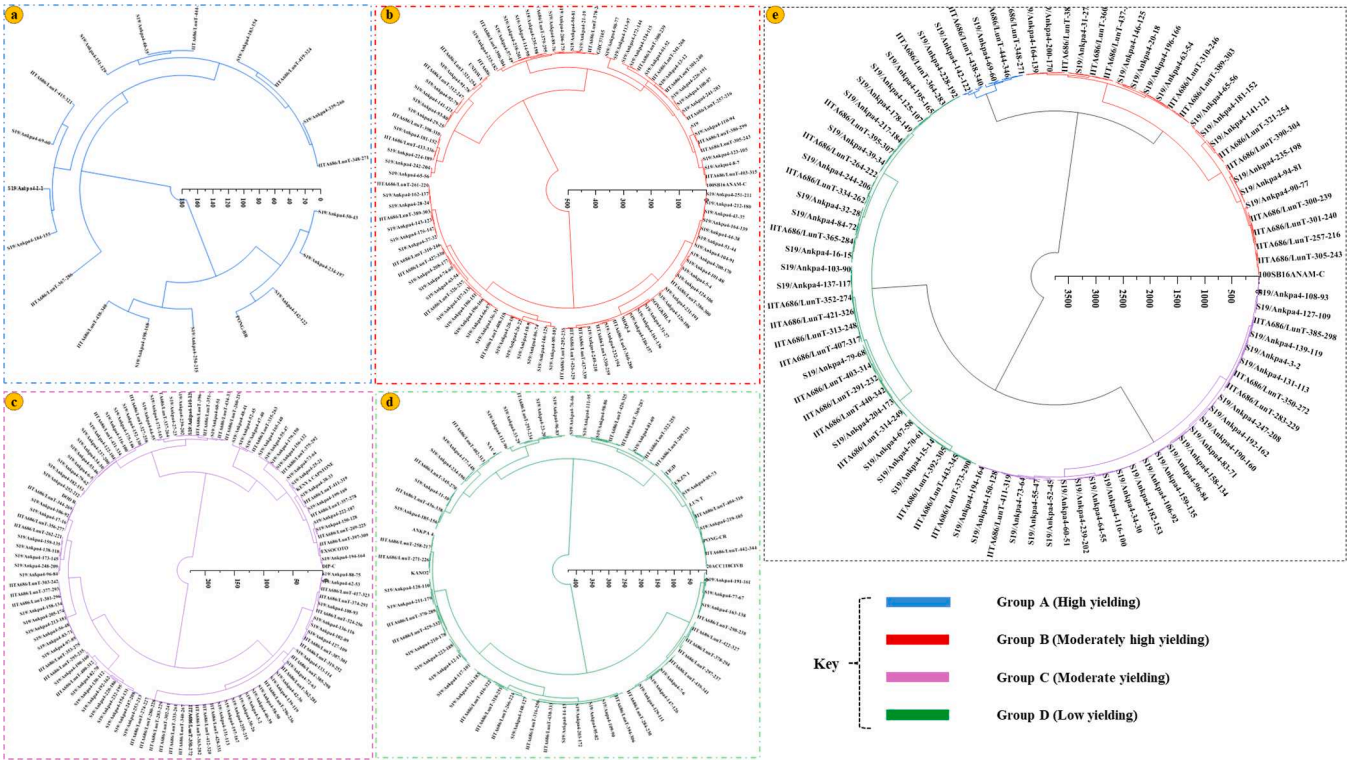

Fig. 4. Agglomerative hierarchical clustering of Bambara groundnut genotypes using agronomic traits. Different colours represent different clusters. (a) high-yielding genotypes, (b) moderately high-yielding genotypes, (c) moderate-yielding genotypes, (d) low-yielding genotypes and (e) combined AHC for all clusters.

vegetative growth. The strong correlation between PL and pH ($r = 0.86$, $p = 0.011$) reflects coordinated growth patterns, while internode length (IL) showed weak but significant negative correlations with DE ($r = -0.23$, $p = 0.048$) and DFF ($r = -0.24$, $p = 0.05$), indicating a potential trade-off between stem elongation and phenological development. For breeding, these correlations suggest that selection for early emergence may indirectly improve vegetative vigour and synchronise flowering, which is advantageous for achieving uniform crop stands and synchronous maturation—traits highly valued by farmers (Gerrano et al., 2021). Moreover, depending on production goals, managing internode length could offer a way to optimize plant architecture for increased stability or improved canopy structure.

The positive associations among vegetative (pH, PL) and reproductive (DE, DFF) traits likely reflect shared hormonal regulation (Depuydt and Hardtke, 2011; Vanstraelen and Benkova, 2012). This integrated growth suggests that breeders can employ multi-trait selection indices to improve key traits linked to yield potential and crop management efficiency. For instance, combining selection for early emergence, optimal plant height, and favourable flowering time could yield genotypes with enhanced performance under diverse farming conditions.

Principal component analysis (PCA) further illustrated the multivariate nature of trait interactions (Table 8). The strong clustering of phenological and vegetative traits in PC1 highlights the integrated development of plant architecture and growth dynamics (Gottlieb et al., 2004). This finding underscores the importance of balanced selection strategies; breeding programs must carefully manage trait interdependencies to avoid unintentional trade-offs when selecting desirable characteristics (Dwivedi et al., 2021). For practical application, breeders could prioritize selection along PC1 to develop genotypes with optimal combinations of early vigour, pH, and synchronized flowering—traits that enhance crop uniformity and facilitate management.

Productivity traits separated from growth traits in PC2 highlight opportunities for independent selection of yield-related traits, enabling breeders to fine-tune yield potential without compromising plant architecture. In addition, PC3 and PC4 revealed structural traits (canopy width and IL) as distinct axes of variation, suggesting these traits can be modified independently to optimize light capture or plant stability. Breeders could exploit this by selecting canopy structures that maximize radiation use efficiency while maintaining robust stems for lodging resistance—important under high-density planting or windy environments.

The cumulative variance explained (91.165 % by PC1–PC4) demonstrates that these components effectively capture phenotypic diversity, offering a robust framework for multi-trait selection (Table 8). Breeding programs can use this framework to design ideotypes tailored for specific production environments—whether high-yield systems with ample resources or stress-prone settings requiring resilience and resource-use efficiency. Furthermore, farmers could benefit from adopting genotypes selected for early emergence and uniform flowering, simplifying crop management, improving harvest timing, and reducing post-harvest losses.

This study provides valuable phenotypic insights to guide breeding strategies and inform practical recommendations for Bambara groundnut breeding and cultivation. Future breeding programs should leverage the observed trait correlations and PCA patterns to develop ideotypes aligned with breeder and farmer priorities—yield, adaptability, ease of cultivation, and stress resilience. Additionally, participatory breeding approaches involving farmers could help fine-tune trait combinations to match diverse local preferences and production systems, accelerating adoption and impact.

Conclusion

Despite its status as an underutilized crop, BGN exhibits significant agro-morphological diversity, as evidenced by the evaluation of recombinant inbred lines derived from four distinct landraces. The findings reveal considerable genetic variation in growth, flowering, yield, and morphological traits, providing a solid foundation for breeding programs to improve agronomic performance and adaptability. The

significant differences observed among genotypes for quantitative and qualitative traits, alongside the high Shannon-Weiner diversity index, demonstrate the crop's rich genetic reservoir. This diversity offers opportunities for selecting and developing high-yielding, climate-resilient cultivars. Furthermore, advancements in artificial hybridization techniques, such as those pioneered at the University of Nottingham, highlight the feasibility of overcoming BGN's reproductive barriers to enable targeted breeding efforts. This research contributes to bridging the knowledge gap in BGN improvement by providing insights into its genetic and phenotypic variability. By leveraging this diversity, BGN can play a pivotal role in enhancing food security, supporting sustainable agriculture, and addressing the nutritional needs of marginalized populations, particularly in drought-prone regions. Future studies should focus on molecular characterization and genome-wide association studies to further identify key traits linked to environmental resilience and yield optimization, ensuring sustainable use of BGN as a cornerstone of global food systems.

CRediT authorship contribution statement

Amanda Ruzive: Formal analysis, Methodology, Data curation, Investigation, Conceptualization, Writing – original draft. **Laurencia Govender:** Writing – review & editing, Supervision. **Takudzwa Mandizvo:** Data curation, Writing – review & editing, Software, Visualization. **Admire Isaac Shayanowako:** Writing – original draft, Formal analysis, Conceptualization, Methodology, Writing – review & editing, Supervision, Visualization, Data curation. **Tatenda Musimwa:** Writing – review & editing. **Hui Hui Chai:** Conceptualization, Funding acquisition, Resources, Writing – review & editing, Methodology. **Festo Massawe:** Conceptualization, Writing – review & editing, Resources, Funding acquisition. **Sean Mayes:** Conceptualization, Writing – review & editing. **Julia Sibiya:** Resources, Writing – review & editing, Conceptualization. **Tafadzwanashe Mabhaudhi:** Methodology, Conceptualization, Supervision, Writing – review & editing, Funding acquisition, Resources.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

Acknowledgements

The Future Food Beacon (under BamBREED programme), University of Nottingham (UK and Malaysia), supported and funded this work.

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