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Summary

Determination of hybrids that are outstanding in performance requires the study of the morphological and phenological characteristics that contribute to crop yield and agronomics. This study explores the performance of 20 sorghum hybrids during the 2022 and 2023 growing seasons in Wamego, Kansas, United States (U.S.), focusing on yield dynamics, crop phenology traits, and canopy structures. Hybrid HYB7 consistently demonstrated superior yields, reaching 157 and 147 bu/a in 2022 and 2023, respectively. Conversely, hybrids 'HYB4' to 'HYB2' exhibited lower productivity. Principal component analysis highlighted key variables influencing grain yield, revealing positive correlations within grain yield, grain filling duration, leaf length, and leaf width at maturity. Clustering identified three distinct hybrid groups, with Cluster 2 standing out for higher yields. These results provide valuable breeding insights and foundational knowledge for future research evaluating sorghum canopy structure under different climatic conditions.

Introduction

Sorghum (*Sorghum bicolor* L.) is predominantly cultivated within the sorghum belt encompassing states such as Kansas, Texas, Colorado, Oklahoma, and South Dakota (Ciampitti and Prasad, 2020). Globally, the US stands as a significant contributor, accounting for 17% of the total sorghum production (FAOSTAT, 2022). Farmers favor sorghum cultivation due to the crop's comparatively low production costs, remarkable resilience to various abiotic stresses, and the growth of substantial biomass that enhances soil's physical and chemical properties (Doggett, 1991). Sorghum's capacity to sustain yields in challenging conditions is noteworthy, particularly during drought (Kresovich et al., 2005). Advancements in grain sorghum yield in the United States have been achieved through modifications in the interactions among genotype (G), environment (E), and agronomic management (M) (Ciampitti et al., 2019, 2020). The canopy architecture plays a key role in explaining this tolerance (Kholová et al., 2014). The objective of this study is to explore the relationship among canopy structures, phenology traits, and grain yield.

Materials and Methods

The research project was conducted during the 2022 and 2023 growing seasons at the Corteva Agriscience Experimental Station in Wamego, KS, U.S. Twenty sorghum hybrids were sown in a randomized complete block design. The planting dates were June 15 and June 8 for the seasons 2022 and 2023, respectively.

Each plot consisted of 8 rows with an interrow space of 30 in., with three repetitions. Twelve plants per plot were selected and from those, 4 plants were sampled at three different growth stages: V7, Flowering (FL), and Maturity (MT). The number of expanded leaves was recorded weekly to determine the correct sampling moment to growth stage. During those instances, the following parameters were evaluated: leaf area index at v7 (LAI V7), leaf area index at flowering (LAI FW), leaf area index at maturity (LAI MT), leaf width at flowering (LW FW), leaf width at maturity (LW MT), leaf length at flowering (LL FW), leaf length at maturity (LL MT), days to flowering (DTFL), days to maturity (DTMT), total number of leaves (LN), total plant height at flowering (HP), and grain-filling period (GF) and grain yield (Yield).

The statistical analysis was performed using R software (R Core Team, 2023). A principal component analysis was performed to evaluate association among traits with the dataset. Hybrids were grouped into clusters. An unsupervised hierarchical algorithm was used to group hybrids into clusters. Boxplots were used to visualize trait distribution (yield, canopy, and phenological traits) by cluster.

Results

The highest yields were consistently achieved by hybrid 'HYB7' in both years, producing 157 and 147 bu/a for 2022 and 2023, respectively. In contrast, hybrids 'HYB4' to 'HYB2' demonstrated the lowest results, with 65 and 81 bu/a for the respective years.

For DTFL, the earliest was observed in 'HYB19' at 45 days, while 'HYB4' exhibited the most extended period, reaching 78 days. DTMT ranged from 89 days ('HYB19') to 119 days ('HYB5'). Hybrid 'HYB16' recorded the highest plant height at 98 in., while hybrid 'HYB14' had the lowest at 42 in., both in the 2022 season. In terms of LN, 'HYB4' and 'HYB2' exhibited the greatest number of leaves (22 leaves) in both periods. The GF, from flowering to maturity, ranged from 28 to 53 days for all hybrids.

The principal component analysis (PCA) showed that the first dimension (Dim 1), explaining 44% of the variability, was mainly governed by days to flowering (DTFL), days to maturity (DTMT), leaf number (LN), leaf length at flowering (LL FW), and leaf width at flowering (LW FW). The second dimension (Dim 2) explained an additional 19% of the variability. Furthermore, the PCA displayed positive correlations with yield and grain filling (GF), leaf length at maturity (LL MT), and leaf width at maturity (LW MT) (Figure 1 B).

Figure 2 A shows the clustering of hybrids into three groups explained over 50% of the variation. Cluster 1 included eight hybrids, Cluster 2 included four, and Cluster 3 included eight. The distribution of the hybrid groups in the PCA indicated that Cluster 2 presented attributes related to higher yields, while Cluster 1 exhibited broader characteristics (Figure 2 B).

Boxplots in Figure 3 summarize the description of canopy variables for each hybrid group. Cluster 1 showed the highest variability in most traits for canopy and phenology, while Cluster 2 exhibited the highest and most stable yield. Furthermore, Cluster 2 showed the highest GF duration value (45 days) while. Maintaining high LL MT and LW MT compared to Clusters 1 and 3. Cluster 3, characterized by shorter days to flowering (less than 55 days) and days to maturity (less than 100 days), expressed a lower leaf number (~17 leaves). Clusters 2 and 3 showed similar yield mean and variability, and similar Leaf Area Index at maturity (LAI MT).

Conclusion

These findings contribute to understanding the diverse characteristics of sorghum hybrids and their implications for yield. Total days to flowering, days to maturity, plant height, and leaf number presented significant diversity among sorghum hybrids. Notably, the most pertinent plant canopy and physiological traits were a larger Leaf Area Index (LAI) at maturity, characterized by longer and wider leaves, along with an extended duration of the grain-filling period. Clustering identified three distinct groups, highlighting Cluster 2 as particularly promising for higher yields. These findings offer critical insights for optimizing sorghum hybrid selection and cultivation strategies.

Acknowledgments

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References

Ciampitti, I. A., Prasad, P. V. V., Schlegel, A. J., Haag, L., Schnell, R. W., Arnall, B., & Lofton, J. (2019). Genotype× environment× management interactions: US sorghum cropping systems. Sorghum: A state of the art and future perspectives, 58, 277-296. *https://doi.org/10.2134/agronmonogr58.c13*.

Ciampitti, I. A., & Prasad, P. V. (2020). Sorghum: state of the art and future perspectives. *https://doi.org/10.2134/agronmonogr58*.

Doggett, H. (1991). Sorghum history about Ethiopia. *Plant genetic resources of Ethiopia*, 140-159.

Food and Agricultural Organization of the United Nations (FAO). (2020). Crops and livestock products. Sorghum. 2019. FAO. *https://www.fao.org/faostat/en/#data/QCL/visualize*.

Kholová, J., Murugesan, T., Kaliamoorthy, S., Malayee, S., Baddam, R., Hammer, G. L., ... & Vadez, V. (2014). Modeling the effect of plant water use traits on yield and stay-green expression in sorghum. Functional Plant Biology, 41(11), 1019-1034.

R Core Team (2023). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL *https://www.R-project.org/*.

Sorghum Genomics Planning Workshop Participants. (2005). Toward sequencing the sorghum genome. A US National Science Foundation-sponsored workshop report. *Plant Physiology*, 138(4), 1898-1902. doi: 10.1104/ pp.105.065136

Table 1: Mean and standard deviation of the evaluated traits for the three phenological states across hybrids

				V7		Flowering												Maturity									
		Yield (bu/ac)		LAI		LAI		Leaf Width (in)		Leaf Length (in)		DTFL		Leaf num		Height (in)		LAI		Leaf Width (in)		Leaf Length (in)		DTMT		GF	
Year	Hybrid	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
2022	HYB1	87.22	14.58	0.63	0.11	4.57	0.82	3.09	0.17	26.70	0.34	62	2	20	1	64.93	9.01	3.41	0.39	2.98	0.20	27.46	2.05	109	4	46	4
2022	HYB2	84.70	24.19	0.71	0.23	5.02	0.39	2.94	0.17	23.17	2.08	64	6	21	1	54.95	4.62	2.98	0.98	2.68	0.25	27.07	1.51	110	2	46	5
2022	HYB3	134.86	8.08	0.75	0.06	5.18	0.34	3.01	0.17	24.23	2.38	60	1	20	1	55.29	1.26	2.49	0.27	2.64	0.15	26.40	0.83	106	4	46	4
2022	HYB4	97.64	39.65	0.61	0.20	5.15	0.83	2.91	0.13	25.60	1.93	64	6	22	1	50.04	11.45	3.44	1.08	2.87	0.27	27.02	1.94	108	6	44	2
2022	HYB5	145.10	12.16	0.75	0.49	4.70	0.04	2.83	0.19	21.99	2.77	60	2	20	1	49.01	1.22	2.84	0.88	2.81	0.11	25.85	0.99	111	0	51	2
2022	HYB6	133.05	9.88	0.67	0.16	4.65	0.49	2.74	0.14	22.20	1.01	56	0	18	1	45.69	3.26	2.58	0.31	2.64	0.10	26.21	1.44	109	4	53	4
2022	HYB7	146.97	5.05	0.64	0.06	4.24	0.57	2.76	0.23	22.38	2.67	59	2	19	0	49.56	2.62	2.41	0.62	2.70	0.08	26.05	1.98	109	4	50	6
2022	HYB8	139.31	4.29	0.68	0.05	4.08	0.30	2.61	0.14	21.93	1.86	56	1	18	1	48.34	6.36	2.09	0.16	2.52	0.15	26.45	1.30	106	4	50	4
2022	HYB9	129.99	8.28	0.71	0.10	4.88	0.55	2.70	0.15	23.45	1.15	56	0	19	0	47.17	2.76	2.46	0.29	2.73	0.07	27.29	0.71	105	3	49	3
2022	HYB10	133.22	4.11	0.61	0.01	4.92	1.21	2.61	0.17	21.80	1.16	56	0	20	1	50.97	2.09	2.70	0.27	2.56	0.08	26.28	1.43	108	4	52	4
2022	HYB11	116.51	4.46	0.55	0.23	3.39	0.08	2.54	0.07	19.64	1.23	48	4	18	1	45.25	1.26	2.44	0.17	2.60	0.08	25.15	1.07	96	6	48	2
2022	HYB12	130.31	18.91	0.61	0.20	4.33	0.39	2.77	0.03	23.70	2.30	56	0	19	0	49.84	0.96	2.51	0.59	2.57	0.13	25.79	0.61	105	3	49	3
2022	HYB13	134.51	3.57	0.70	0.07	3.82	0.62	2.45	0.05	21.29	1.15	49	6	18	1	47.92	3.31	2.49	0.68	2.60	0.04	25.24	1.40	99	5	49	1
2022	HYB14	118.26	7.08	0.60	0.14	3.47	0.54	2.27	0.11	18.38	0.78	46	1	20	4	41.67	4.80	2.68	0.35	2.46	0.15	23.70	0.97	90	1	45	1
2022	HYB15	125.60	3.49	0.70	0.16	3.55	0.41	2.35	0.12	19.64	0.23	48	4	19	3	49.51	3.19	2.27	0.43	2.54	0.08	23.84	2.07	96	7	48	3
2022	HYB16	138.52	10.64	0.60	0.16	3.87	0.40	2.72	0.21	21.28	2.48	55	2	19	1	98.28	90.23	2.38	0.09	2.57	0.11	25.08	0.59	98	3	43	3
2022	HYB17	119.13	4.52	0.54	0.07	3.42	0.16	2.34	0.12	21.29	1.04	49	6	18	2	46.93	0.76	1.83	0.17	2.45	0.09	24.56	3.58	92	5	43	2
2022	HYB18	118.61	5.77	0.55	0.14	3.47	0.45	2.53	0.10	18.43	0.89	46	0	17	2	47.88	2.03	2.33	0.09	2.65	0.13	23.88	0.25	92	4	46	4
2022	HYB19	107.61	10.03	0.71	0.10	2.53	0.35	2.53	0.07	19.15	0.43	45	1	16	1	43.61	0.37	2.49	0.09	2.66	0.11	23.71	1.33	89	0	44	1
2022	HYB20	111.10	5.67	0.83	0.42	2.97	0.19	2.61	0.11	18.07	0.75	46	0	17	2	42.75	3.65	2.48	0.10	2.76	0.05	23.74	1.15	90	1	44	1
2023	HYB1	86.62	20.50	0.90	0.08	2.82	0.19	4.29	0.03	23.56	0.53	78	0	18	1	69.36	5.87	1.15	0.03	3.57	0.41	19.35	0.33	116	4	38	4
2023	HYB2	81.17	22.60	0.61	0.08	4.17	0.53	4.93	0.38	25.63	1.29	76	4	20	1	57.13	0.50	1.15	0.31	3.52	0.33	18.84	0.88	113	0	37	4
2023	HYB3	106.09	30.56	0.67	0.29	4.17	1.03	4.99	0.13	26.62	2.12	73	8	19	1	56.61	1.85	1.51	0.23	3.71	0.15	22.22	2.22	108	4	35	7
2023	HYB4	64.59	49.20	0.60	0.00	4.05	0.50	4.89	0.32	26.64	1.39	78	0	20	1	57.48	1.47	1.67	0.27	3.72	0.31	19.76	1.08	116	4	38	4
2023	HYB5	82.46	0.00	0.91	0.00	3.77	0.00	4.87	0.00	23.97	0.00	78	0	17	0	45.58	0.00	1.71	0.00	3.12	0.00	21.25	0.00	119	0	41	0
2023	HYB6	104.43	2.54	0.85	0.05	4.17	0.28	4.52	0.17	24.94	1.09	64	0	17	0	53.43	3.29	0.97	0.13	4.93	2.21	25.09	7.05	110	5	46	5
2023	HYB7	157.33	0.00	0.58	0.00	4.91	0.00	5.01	0.00	24.31	0.00	64	0	18	0	53.51	0.00	1.39	0.00	3.50	0.00	21.98	0.00	106	0	42	0
2023	HYB8	89.52	23.07	0.83	0.14	4.75	1.01	4.75	0.34	24.67	2.89	64	0	19	1	48.39	2.84	1.42	0.32	4.43	1.10	24.41	0.97	111	4	47	4
2023	HYB9	125.13	17.09	0.80	0.04	4.65	0.52	4.20	0.40	26.61	0.84	64	0	19	1	55.41	2.82	1.44	0.36	4.71	1.58	24.57	4.70	104	4	40	4
2023	HYB10	107.37	48.60	0.81	0.11	3.97	0.83	4.47	0.33	24.92	1.42	64	0	18	1	50.86	7.72	1.99	0.74	5.71	1.80	28.78	5.36	106	7	42	7
2023	HYB11	91.38	10.83	0.85	0.16	3.65	0.34	4.25	0.26	24.52	0.13	57	0	16	0	44.96	1.08	1.30	0.16	4.87	0.39	24.52	0.70	92	0	35	0
2023	HYB12	140.27	24.48	0.50	0.00	5.49	0.22	3.79	0.17	26.19	1.40	64	0	19	1	53.64	2.29	2.09	0.94	4.53	0.46	24.45	2.58	99	10	35	10
2023	HYB13	102.84	20.29	0.71	0.21	3.43	0.52	3.66	0.62	23.92	1.19	59	4	17	0	45.48	2.72	1.07	0.28	4.37	1.78	23.45	1.70	97	8	37	4
2023	HYB14	124.65	7.73	0.77	0.26	3.95	0.14	4.30	0.14	23.77	0.25	57	0	17	0	42.26	1.82	1.62	0.17	4.54	0.44	23.70	1.91	92	0	35	0
2023	HYB15	109.27	5.60	0.83	0.11	3.83	0.37	3.94	0.35	25.12	0.41	59	4	17	1	50.78	1.48	1.30	0.46	4.45	1.03	24.31	1.75	92	0	33	4
2023	HYB16	93.53	23.28	0.83	0.17	3.84	0.54	4.59	0.40	24.75	1.00	64	0	17	0	51.28	5.23	1.92	1.54	4.28	0.42	23.60	1.32	92	0	28	0
2023	HYB17	93.40	19.26	0.77	0.23	3.00	0.32	4.10	0.45	25.15	0.40	57	0	15	1	45.18	0.38	1.14	0.14	4.15	1.17	24.46	1.10	92	0	35	0
2023	HYB18	102.18	29.60	0.79	0.25	3.33	0.17	4.18	0.92	23.35	1.96	57	0	16	1	47.30	1.87	0.96	0.31	4.25	0.75	21.74	1.49	92	0	35	0
2023	HYB19	82.30	11.44	0.80	0.10	2.39	0.11	3.77	0.16	23.63	0.53	57	0	15	1	43.93	0.98	1.40	0.16	4.59	0.24	23.85	0.53	92	0	35	0
2023	HYB20	98.72	1.52	0.74	0.20	2.63	0.08	3.86	0.29	22.24	1.18	57	0	15	1	45.09	0.69	1.95	0.72	4.56	0.27	23.76	1.39	92	0	35	0

LAI = leaf area index. DTFL = days to flowering. DTMT = days to maturity. GF = grain filling period. SD = standard deviation

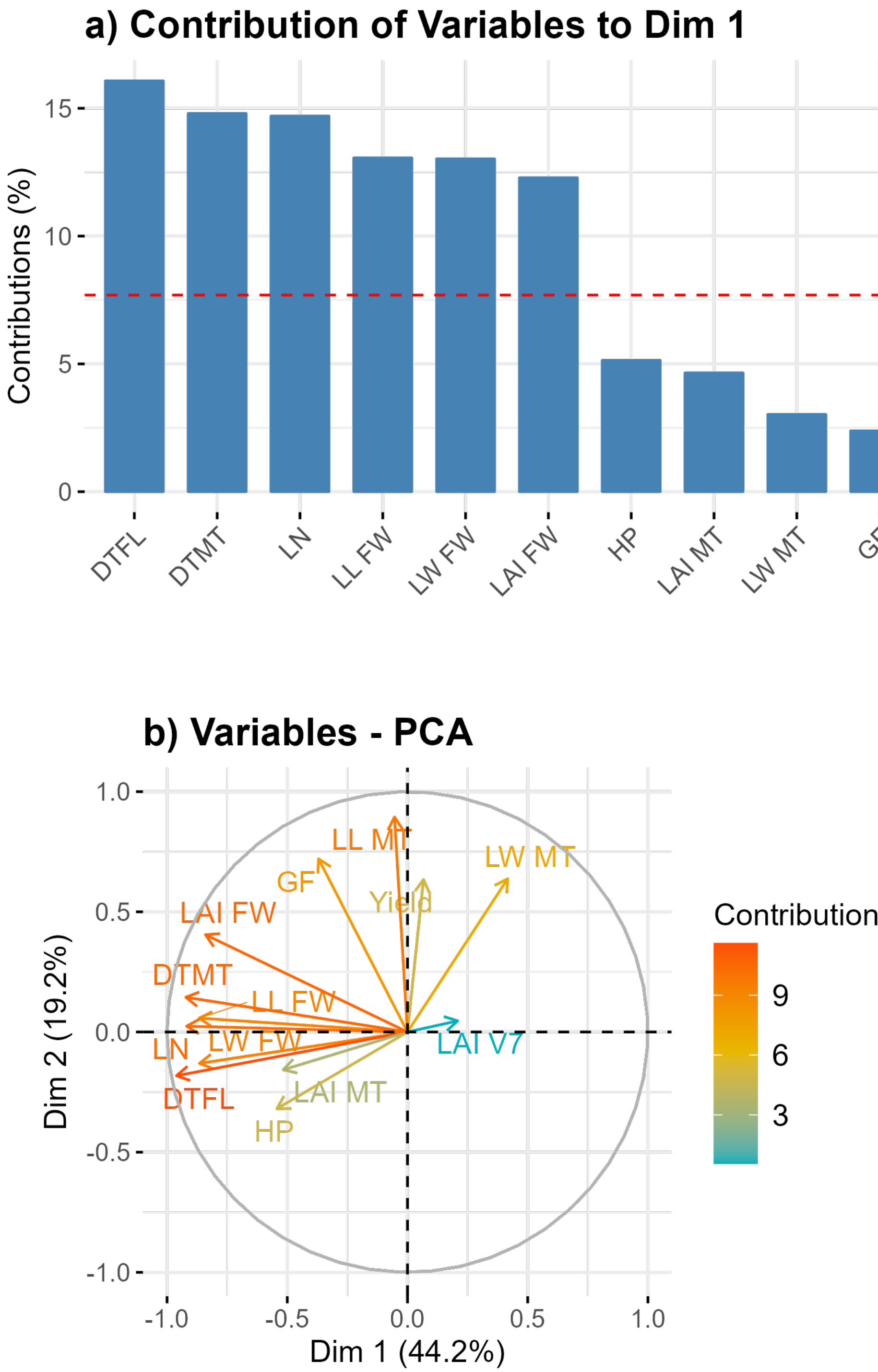

Figure 1. a) Relative proportion of variability explained by Principal Component 1 attributable to each variable's contribution. The dashed line corresponds to the expected value of the contribution where it is uniform. Analysis is across years 2022-23. b) Principal component analysis explaining the association between canopy architecture traits. Arrows represent vectors, which show the magnitude and direction (positive/negative) across variables. LAI FW = leaf area index at flowering, LW FW (in) = leaf width at flowering, LL FW (in) = leaf length at flowering, DTFL = days to flowering, GF = grain filling period, LAI MT = leaf area index at maturity, LW MT (in) = leaf width at maturity, LL MT (in) = leaf length at maturity, DTMT = days to maturity, HP = height plant, LAI V7 = leaf area index at v7, LN = leaf number.

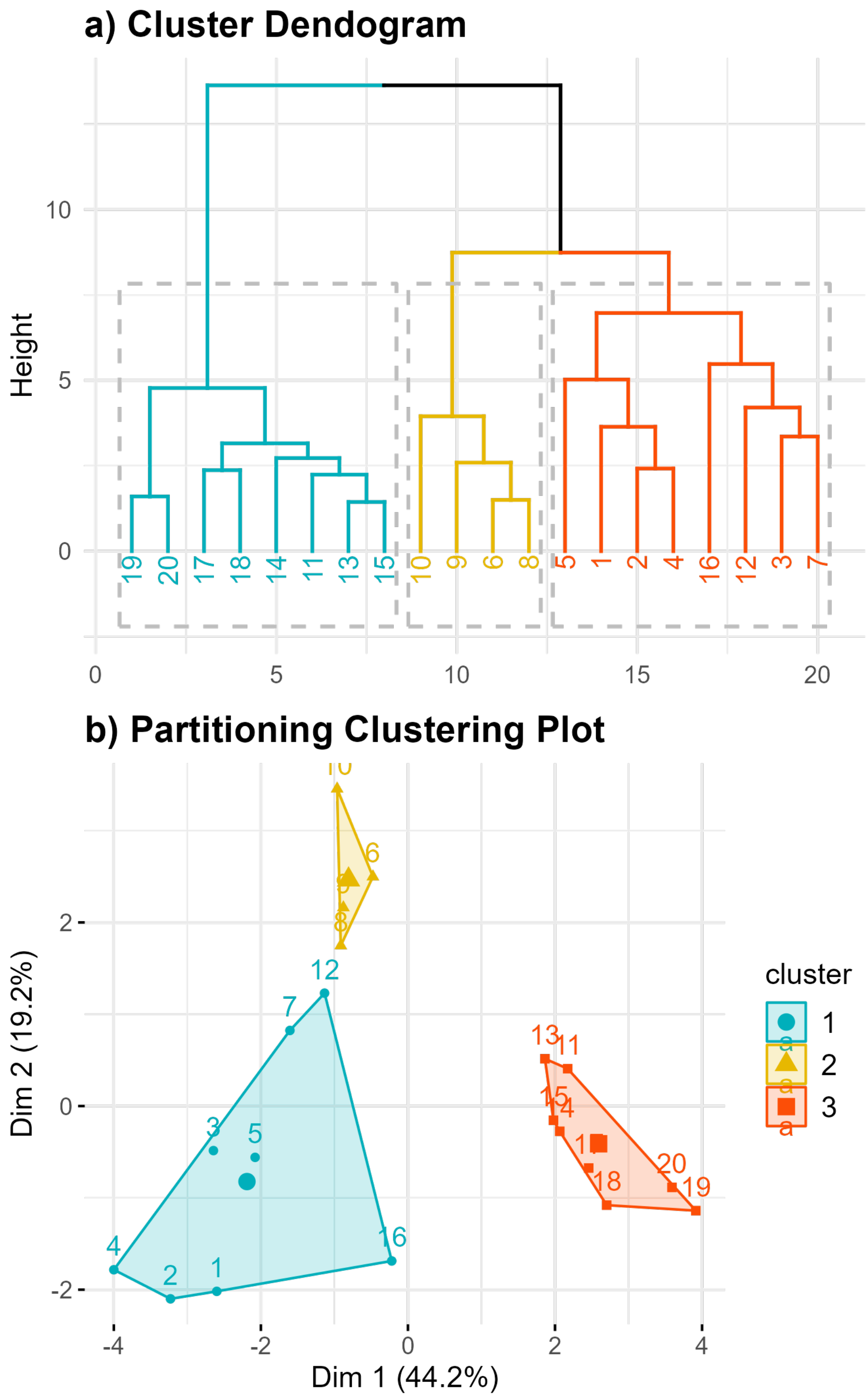

Figure 2. a) Cluster Dendrogram, the dashed box spans the different divisions of hybrid groups. Hierarchical clustering was calculated using Rcut to obtain 3 clusters for the hybrids evaluated across the seasons 2022 and 2023. b) Partitioning Clustering Plot represents the dispersion of hybrids within the clusters in the PCA analysis. Each color corresponds to a cluster.

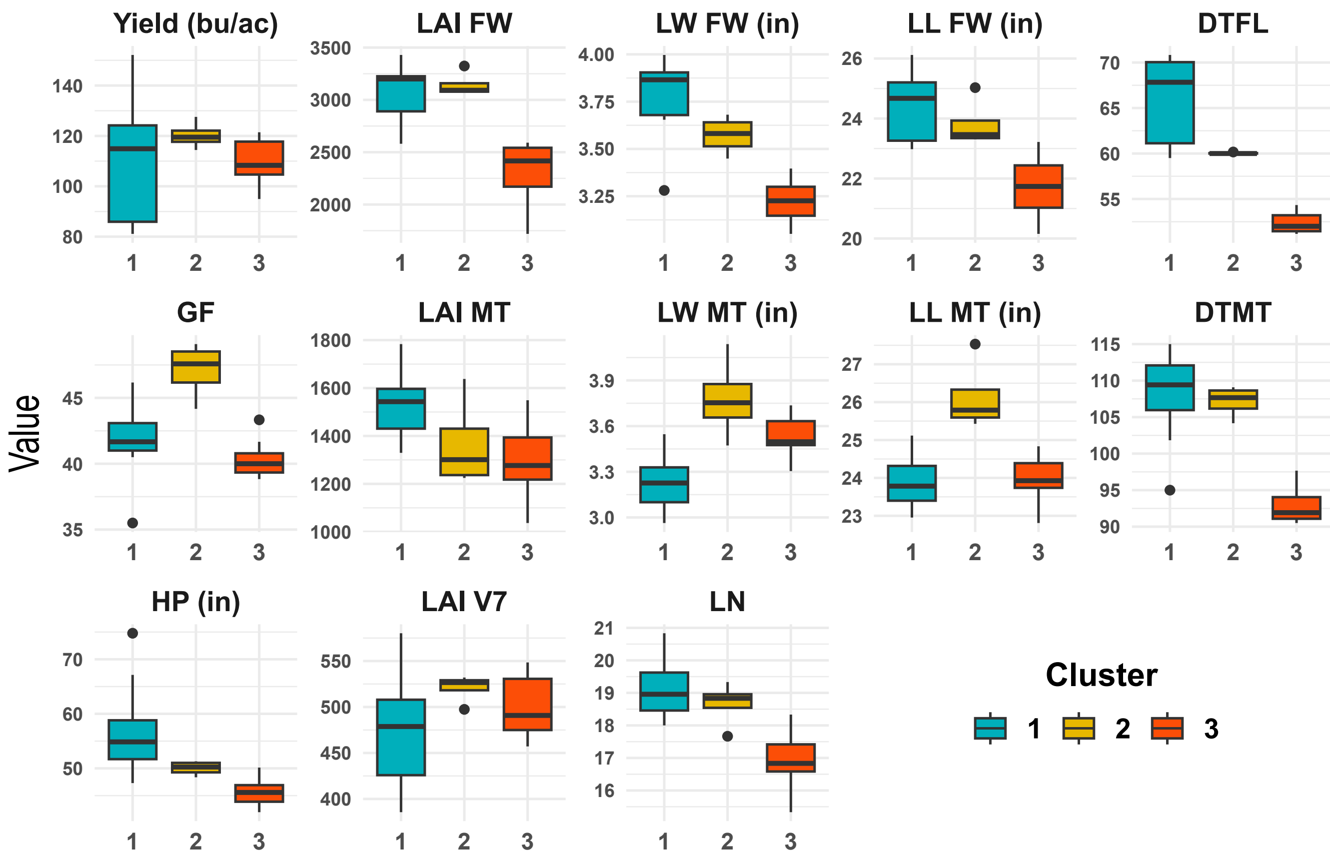

Figure 3. Summary of canopy architecture and crop phenology traits between different hybrid clustering. LAI FW = leaf area index at flowering, LW FW (in) = leaf width at flowering, LL FW (in) = leaf length at flowering, DTFL= days to flowering, GF = grain filling period, LAI MT = leaf area index at maturity, LW MT (in) = leaf width at maturity, LL MT (in) = leaf length at maturity, DTMT = days to maturity, HP = height plant, LAI V7 = leaf area index at v7, LN = leaf number. Each color corresponds to a cluster.