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EVALUATION OF GERMPLASM TO IDENTIFY GENETIC DIVERSITY AND CLIMATE RESILIENT HIGH YIELDING GENOTYPES IN CHICKPEA FOR FOOD SECURITY

Original Article

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ABSTRACT

Background: Chickpea (*Cicer arietinum* L.) is a vital legume crop cultivated extensively in arid and semi-arid regions due to its high nutritional value and adaptability. However, its productivity is severely constrained by environmental stresses, particularly drought and irregular sowing schedules. Climate-induced fluctuations in temperature and rainfall patterns have intensified the challenge, affecting crop phenology and yield potential. Identifying genetically diverse and climate-resilient genotypes is essential to sustain chickpea production in changing agroecological conditions.

Objective: To evaluate genetic diversity and identify high-yielding, climate-resilient chickpea genotypes under different sowing time regimes.

Methods: A total of 200 Desi chickpea genotypes, including advanced lines and commercial varieties, were assessed during the 2024–2025 cropping season at the Pulses Research Institute, Faisalabad. The experiment used a randomized complete block design with three replications under two sowing dates—2nd November (D1) and 22nd November (D2). Phenological, morphological, and yield-related traits were recorded, and comparative analyses were conducted to determine drought response.

Results: Under D2 conditions, germination percentage decreased to 70–90%, with genotypes like D-97036 and D-95081 most affected. Days to 50% flowering and maturity were shortened by 15–25 days, indicating a rapid drought escape strategy. Plant height, branching, and pod number were significantly reduced; D-91038's height declined from 89.9 cm to 65.2 cm. The 100-grain weight dropped by up to 43.3%, and grain yield per plot decreased in all genotypes. CAM-94 and D-97054 demonstrated superior performance under D2 stress.

Conclusion: The study identified genotypes with consistent yield and phenological stability under late sowing and drought conditions, offering promising candidates for climate-resilient chickpea breeding programs.

Keywords: Agronomic traits, Chickpea, Climate resilience, Drought tolerance, Genetic diversity, Late sowing, Yield performance.

INTRODUCTION

Chickpea (*Cicer arietinum* L.), a self-pollinated leguminous crop of the Fabaceae family, plays a pivotal role in global food security, particularly in arid and semi-arid regions. It is primarily grown in two distinct types: Desi (brown gram) and Kabuli (white gram), both of which are valued for their nutritional and agronomic importance. Known for their high protein content—ranging between 18% and 25%—chickpeas are widely acknowledged as an affordable plant-based protein source and a viable dietary alternative to meat (1). Among leguminous pulses, chickpea is recognized for having the highest protein bioavailability, further adding to its significance in vegetarian and protein-deficient populations (2). Additionally, chickpea seeds offer a rich supply of micronutrients such as iron—approximately 5.0 mg per 100 grams—and water-soluble vitamins (3). In Pakistan, chickpea holds a dominant position in pulse cultivation, occupying nearly 73% of the total area under pulses and contributing about 76% to total national pulse production. Despite this, production during the 2023–2024 cropping season was estimated at only 0.36 million tonnes, failing to meet the domestic consumption demand that ranges between 0.40 and 0.70 million tonnes (4). This disparity highlights a critical supply gap, often met through imports. The crop spans approximately one million hectares, thriving in both irrigated and rainfed zones, with the Thal desert being a particularly vital production area due to chickpea's inherent tolerance to drought-like conditions (5,6). Nevertheless, despite its hardiness, chickpea yield is constrained by a range of abiotic and biotic stressors, with water scarcity being the most severe. Globally, more than one-third of the population lives in water-stressed regions, a challenge exacerbated by climate change, which is expected to increase the frequency, intensity, and duration of droughts (7).

The impact of climate variability on agriculture—especially in countries like Pakistan, ranked among the top ten most climate-vulnerable nations—is profound, leading to yield fluctuations and increasing threats to food security (8). Changing patterns of temperature and precipitation demand urgent adaptation strategies for climate-sensitive crops such as chickpea. Research suggests that rapid phenological development in legumes could serve as a survival mechanism under such harsh conditions (9). However, chickpea yields continue to vary widely across agroecological zones. In irrigated environments, yields remain stable, while in arid regions, they are often erratic due to inconsistent water availability (10). Traditionally, Desi varieties are preferred for cultivation in dryland areas due to their resilience, whereas Kabuli types are more commonly grown in controlled, irrigated settings (11). This agroclimatic dependency, combined with growing population demands, intensifies the need for developing climate-resilient and high-yielding genotypes. Recent agricultural strategies emphasize the necessity of climate-resilient crop development as a key solution to mitigate the adverse effects of environmental stress. Central to this approach is the evaluation and identification of genetically diverse chickpea lines with strong adaptability to variable climate conditions (12). Such efforts not only reduce dependency on imports but also promote long-term agricultural sustainability. Moreover, revising sowing calendars and adapting genotypes based on updated climatic data has emerged as a fundamental practice in climate-smart agriculture (13). In this context, the present study was undertaken with the objective of assessing genetic diversity and identifying climate-resilient, high-yielding chickpea genotypes suitable for diverse agroecological conditions.

METHODS

The experiment was conducted at the Pulses Research Institute (PRI), Faisalabad, during the 2024–2025 cropping season to assess the performance of Desi chickpea genotypes under different sowing conditions. The study employed a two-factor factorial design under a randomized complete block arrangement with three replications to ensure statistical robustness. Two distinct sowing dates were utilized—2nd November and 22nd November—denoted as D1 and D2, respectively, to simulate environmental variability in early and delayed planting windows. A total of 200 Desi chickpea genotypes were evaluated, including both advanced breeding lines and commercially released varieties, with no explicit exclusion criteria, implying a broad representation of the existing genetic pool (14,15). The genotypes were sown using a dibbler, a traditional manual planting tool, with each plot measuring 2.40 m² and consisting of two rows. Row-to-row and plant-to-plant spacings were maintained at 30 cm and 15 cm, respectively, to ensure uniform growth conditions and avoid inter-plant competition. Throughout the cropping cycle, standard agronomic practices were uniformly applied to all experimental units.

Weed control was achieved manually through hand weeding on an as-needed basis, and plant protection measures were implemented to safeguard against pest and disease outbreaks. The experimental site, Faisalabad, is geographically located at 31.4504° N latitude and 73.1350° E longitude, with an elevation of approximately 189 meters above sea level and a subtropical climate, making it an ideal region for studying drought-tolerant legume performance. Data collection encompassed a comprehensive set of morphological and phenological traits including germination percentage, days to 50% flowering, days to 50% maturity, plant height (cm), number of primary and secondary branches, height of the first pod (cm), number of pods per plant, 100-grain weight (g), and grain yield per plot (g). These variables were selected to reflect both growth performance and yield potential under variable sowing regimes. The study rigorously followed agronomic protocols; ethical approval was obtained from Institutional Review Board (IRB) of the relevant institute.

RESULTS

The experimental results demonstrated clear differences in the performance of chickpea genotypes under the two sowing conditions. Germination percentage under D1 conditions was optimal for most genotypes, ranging between 97% and 100%, indicating favorable early-season moisture and temperature conditions. In contrast, germination under D2 conditions declined significantly, with the lowest values observed in D-97036 (70%) and D-95081 (72%), suggesting adverse impacts of late sowing and water stress on seed viability and early establishment. Days to 50% flowering (DTF50%) were consistently reduced across all genotypes under D2. For instance, D-95013 flowered in 125.2 days under D1 and 105.1 days under D2, while CAM-94 shifted from 115.2 days to 102.2 days. Similarly, days to 50% maturity (DTM50%) were shortened under D2, exemplified by D-97054 which matured in 158.1 days under D1 and 135.2 days under D2. This trend of hastened phenology was universally observed, indicating a drought escape mechanism triggered by environmental stress. A notable decline in plant height was recorded under D2 for all genotypes. D-91038 exhibited the most significant drop from 89.9 cm (D1) to 65.2 cm (D2). Primary branches were also reduced under drought conditions, with D-95081 decreasing from 3.2 (D1) to 2.0 (D2). Secondary branches were similarly affected; for example, D-97054 dropped from 15 to 6 branches between D1 and D2. Pod numbers showed substantial reductions, particularly in D-97036 which declined from 150.6 pods per plant under D1 to 95.9 under D2.

The height of the first pod (HOFP) was also lower under D2, as seen in CAM-94, which dropped from 33.6 cm (D1) to 25.1 cm (D2). This trait, crucial for mechanical harvesting, was compromised due to shortened internodes and limited growth under water deficit conditions. Reductions in 100-grain weight (100GW) were pronounced across all genotypes. For instance, CAM-94 declined from 32.2 g to 22.1 g, and Bittal-21 from 26.8 g to 15.2 g, representing a 43.3% reduction. Such decreases are indicative of limited photosynthate translocation and reduced grain-filling duration under drought stress. Grain yield per plot was consistently higher under D1 across all genotypes. The highest yield under D1 was observed in CAM-94 (1263.1 g), followed by D-97054 (1250.1 g) and D-03026 (1246.2 g). Under D2, these same genotypes recorded 1033.1 g, 1013.2 g, and 1001.1 g respectively, reflecting yield reductions of approximately 18–20%. The most severe absolute decline was seen in D-91038, which dropped from 1100.1 g (D1) to 828.2 g (D2), equating to a 24.7% loss. Bittal-21 also showed a substantial decline from 802.1 g to 675.1 g, despite a relatively low baseline yield.

The observed reduction in grain yield across all genotypes under D2 was a cumulative outcome of compromised vegetative growth, reduced branching, lower pod and grain numbers, and decreased grain weights. Genotypes such as CAM-94 and D-97054 showed comparatively lower relative yield reductions, suggesting intrinsic physiological or morphological traits that confer partial drought resilience. To evaluate the strength of association between yield and key morphological traits, Pearson correlation coefficients were computed. A strong positive correlation was observed between 100-grain weight and grain yield under both sowing conditions, with coefficients of 0.82 under D1 and 0.86 under D2. This indicates that heavier grain weight was a significant determinant of yield across environmental conditions, reaffirming its role as a primary yield-contributing trait. In contrast, plant height exhibited a weak correlation with grain yield under both conditions, with r-values of 0.26 (D1) and 0.11 (D2), suggesting that plant stature alone was not a reliable predictor of final yield under drought or optimal conditions. These findings underscore the importance of grain filling efficiency over vegetative growth for sustaining productivity in chickpea, especially under stress.

Table 1: Meteorological conditions for Faisalabad, Pakistan during 2024-25

Month	Air Temp (ºC)		Differ 1&2	Rel. Humidity %		Pan Evaporation (mm)		Rain fall (mm)	Wind velocity (km hour^{-1}& days)		Dew	Cloudy		Soil Temp (100 cm depth)	Sun Shine Hours		Fog
	Max	Min		8:00 am	5:00 pm	8:00 am	5:00 pm		8:00 am	5:00 pm		Days	Nights		H	M	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
October	34.8	21.4	13.4	80.3	48.1	1.2	2.3	-	1.2/7	2.0/16	31	-	-	30.3	9	1	15
November	27.0	14.8	12.2	88.8	60.9	0.5	1.1	0.2	0.4/3	0.4/3	29	-	1	26.4	4	51	28
December	21.1	6.1	14.9	87.6	53.5	0.6	1.0	TR	1.0/6	1.6/12	31	-	-	20.9	5	56	6
January	21.5	5.5	16.0	88.0	51.5	0.6	1.2	TR	0.5/2	2.4/18	30	1	1	17.9	6	10	7
February	24.7	10.0	14.8	85.7	46.6	0.8	1.4	35.7	0.3/2	4.1/21	22	1	6	19.0	7	00	1
March	29.6	14.2	15.4	73.7	39.4	1.7	2.7	7.3	2.6/16	4.1/26	27	-	4	21.9	9	38	-
April	38.9	21.9	17.0	54.2	32.1	2.8	3.8	5.0	1.6/11	4.4/29	29	-	-	27.4	10	20	38.9

Table 2: Mean Values of phonological, morphological and yield related traits in two different sowing dates during year 2024-2025

Genotypes		GP%	DTF50%	DTM50%	P.H cm	Pri.Br	Sec.br	Pods/p	HOFP (cm)	100GW (g)	GY/P (g)
CAM-94	D1	100%	115.2	155.2	71.1	4	6	82.2	33.6	32.2	1263.1
	D2	90%	102.2	138.2	54.2	3.2	7.1	68.7	25.1	22.1	1033.1
D-97054	D1	100%	110.1	158.1	84.1	3	15	80.3	43.2	31.2	1250.1
	D2	85%	100.2	135.2	61.5	3	6	68.1	30.1	21.1	1013.2
D-03026	D1	92%	108.1	152.1	831	4.1	17	87.2	32.2	31.2	1246.2
	D2	85%	98.1	133.2	53.2	4.1	11	55.2	25.1	20.1	1001.1
D-95013	D1	100%	125.2	160.2	76.2	4	13	85.1	43.1	29.7	1243.1
	D2	85%	105.1	130.2	55.2	3	7	65.2	32.2	20.2	995.2
D-94092	D1	100%	118.2	152.3	81	5	14	89.2	43.1	29.6	1230.1
	D2	85%	98.2	138.2	51.2	3	5	55.2	35.2	19.4	931.2
D-95059	D1	97%	122.1	152.1	72.2	4.1	9.1	97.2	44.1	29.5	1105.1
	D2	75%	105.2	130.2	41.7	2.8	7.1	56.9	30.2	20.1	890.2
D-95081	D1	97%	120.1	150.1	74.1	3.2	9.2	87.1	43.1	29.5	1083.2
	D2	72%	102.2	132.2	55.5	2.0	4.1	44.3	28.2	19.4	863.1
D-91038	D1	97%	118.1	148.1	89.9	4.1	9.1	57.3	49.1	29.3	1100.1
	D2	78%	104.1	134.1	65.2	3.2	6.9	39.7	35.1	20.7	828.2
D-97036	D1	100%	108.4	158.4	82.1	3.8	15.8	150.6	43.1	29.1	862.1
	D2	70%	93.1	133.1	63.7	2.5	9.7	95.9	30.1	16.4	773.2
Bittal-21	D1	95%	106.2	149.1	68	4.1	17.1	89.3	31	26.8	802.1
	D2	75%	95.1	131.1	45.1	3.1	9.1	80.1	25	15.2	675.1

DTF50%: Days to 50% flowering. DTM50%: Days to 50% maturity. P.H: Plant height. Pri.Br: Primary branches. Sec.br: Secondary branches, Pods/P: Pods per plant. HOFP: Height of first pod, 100GW: 100 grain weight.GY/P: Grain yield per p

Table 3: Correlation Between Key Traits and Grain Yield

Trait Pair	Pearson Correlation Coefficient
Plant Height vs Grain Yield (D1)	0.258
Plant Height vs Grain Yield (D2)	0.107
100-Grain Weight vs Grain Yield (D1)	0.824
100-Grain Weight vs Grain Yield (D2)	0.863

Interpretation: A strong positive correlation exists between 100-grain weight and grain yield in both sowing conditions, suggesting it is a reliable yield predictor under drought and optimal environments. A weak correlation was observed between plant height and grain yield, indicating plant height contributes less directly to yield outcomes under variable stress conditions.

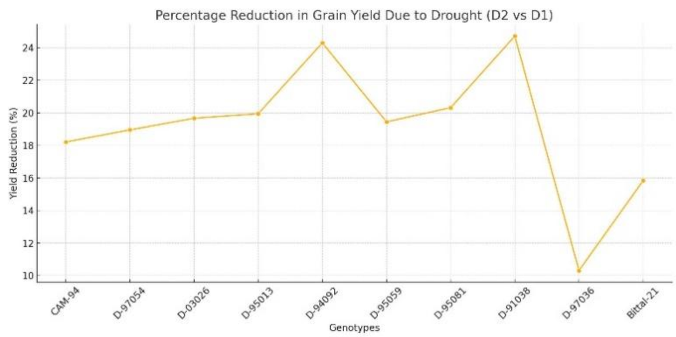

Figure 1 Percentage Reduction in Grain Yield Due to Drought (D2 vs D1)

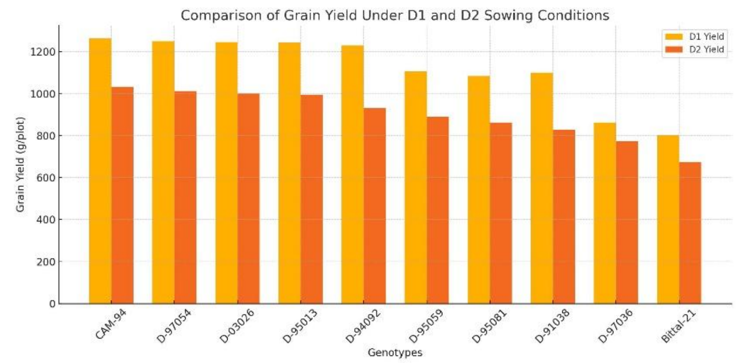

Figure 2 Comparison of Grain Yield Under D1 and D2 Sowing Conditions

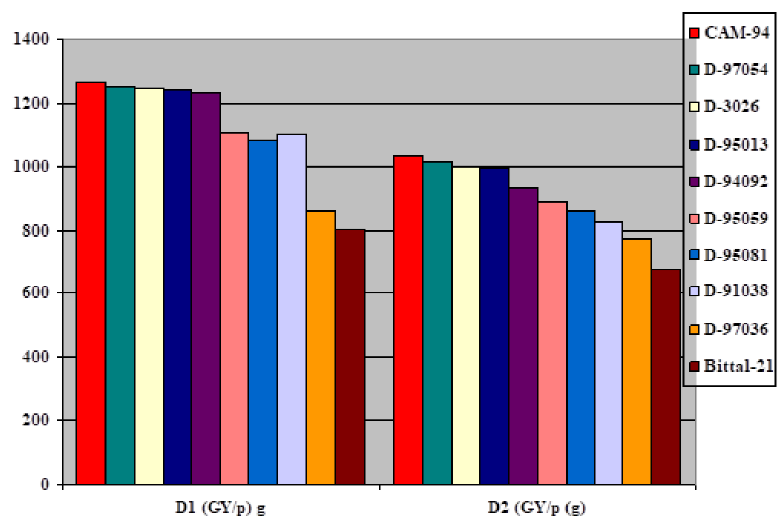

Figure 3 Grain yield (g/per plot) under two sowing dates D1 and D2 in year 2024-2025

DISCUSSION

The findings of this study offer compelling evidence on how altered sowing dates and water stress profoundly influence the phenological and agronomic performance of Desi chickpea genotypes. The observed decline in germination percentage under D2 conditions, particularly in genotypes such as D-97036 and D-95081, underscores the sensitivity of early developmental stages to suboptimal moisture availability. This aligns with prior reports which demonstrated that seed imbibition and enzymatic activation are critically impaired under drought, leading to delayed or reduced germination (16). In contrast, the near-complete germination observed under D1 indicates that timely sowing in moisture-sufficient conditions can effectively optimize seedling establishment. One of the most consistent trends observed across all genotypes was the hastened phenology under D2 conditions. Both days to 50% flowering and maturity were significantly shortened compared to D1, indicating that the plants accelerated their developmental processes to escape prolonged drought stress. This phenomenon reflects a classical drought-escape strategy employed by legumes, facilitated by hormonal cues such as elevated abscisic acid and modulated gibberellin activity, which promote reproductive transition at the expense of vegetative growth (17,18). The findings are consistent with previous research indicating that early flowering and shortened life cycles help crops complete reproduction before the onset of irreversible stress (19-21). However, while early phenology ensures some level of reproductive success, it compromises grain filling duration, which ultimately affects seed weight and yield. The study revealed significant reductions in grain weight under D2, with Bittal-21 showing nearly a 43% decrease, supporting the view that early maturity under drought often limits the source-sink balance and carbohydrate mobilization to developing grains (22,23).

Plant height and branching patterns were similarly impacted under stress, with notable reductions recorded in all genotypes. These vegetative traits are closely linked to photosynthetic surface area and reproductive site availability, and their decline under D2 reflects reduced cell expansion and limited resource allocation. Genotypes like D-91038 experienced a sharp decrease in height from 89.9 cm (D1) to 65.2 cm (D2), which is a clear indicator of gibberellin suppression and impaired nutrient uptake under drought. Likewise, both primary and secondary branches diminished, reducing the number of potential pod-bearing sites. Pod number, a direct determinant of yield, also suffered significantly under D2, with genotypes such as D-97036 exhibiting drastic pod losses due to impaired pollen viability and increased abortion rates, as commonly reported in water-deficit environments (24-26). The decline in height of the first pod (HOFP) further highlights the morphophysiological impacts of stress. Lower pod placement complicates mechanical harvesting and reflects a more compact internode structure, driven by disrupted hormonal regulation. The strong correlation observed between 100-grain weight and final yield in both D1 and D2 indicates that seed weight is a reliable selection trait for drought resilience. In contrast, plant height demonstrated only a weak association with yield, indicating that vegetative growth alone is not sufficient to predict performance under stress (27). This emphasizes the need to focus on reproductive efficiency and grain filling capacity as key breeding targets in chickpea improvement programs.

Yield data further validated the cumulative impact of drought stress on multiple traits. Genotypes such as CAM-94 and D-97054 consistently maintained higher grain yields under both D1 and D2, with minimal relative reductions. These genotypes likely possess intrinsic physiological adaptations, such as superior root architecture, enhanced osmotic regulation, or efficient remobilization of stored assimilates (28,29). Their performance under stress supports their potential as parent lines in breeding programs targeting drought-prone environments. In contrast, genotypes with high baseline yields but significant declines under stress, like D-91038, may lack the plasticity needed to sustain productivity in unpredictable climatic conditions. From a broader agronomic perspective, the findings reaffirm the significance of optimized sowing time in mitigating climate-induced yield penalties. The delay in sowing by merely 20 days (D2 vs D1) coincided with higher temperatures, lower soil moisture, and shortened daylengths—factors that collectively reduced photosynthetic efficiency and biomass accumulation. This compound stress environment mimics realistic climate change scenarios, making these insights highly relevant for future adaptation strategies.

Despite the robustness of phenotypic observations, the study had certain limitations. Notably, the absence of inferential statistics such as ANOVA or confidence intervals limits the strength of comparative conclusions. Furthermore, the lack of a genotype-by-environment interaction analysis restricts understanding of stability across conditions. Inclusion of physiological measurements, such as relative water content, leaf chlorophyll index, or stomatal conductance, could have added valuable depth to the interpretation of stress responses. Future studies should also integrate molecular profiling to identify drought-responsive genes and quantify the heritability of key traits under multi-location trials. Nevertheless, the study's strength lies in its large-scale screening of 200 diverse genotypes under field-based stress conditions, offering a practical evaluation platform for breeding programs. The consistency of responses across morphological, phenological, and yield-related traits enhances the reliability of the findings. By identifying genotypes that combine early maturity with yield stability, the research provides a solid foundation for developing climate-resilient chickpea cultivars tailored to rainfed and semi-arid agroecosystems.

CONCLUSION

This study successfully identified substantial genetic variability among Desi chickpea genotypes in response to altered sowing times and drought stress, highlighting critical traits such as early flowering, maturity, and stable grain weight as key indicators of climate resilience. The findings demonstrate that specific genotypes possess adaptive physiological and morphological traits that enable them to maintain yield performance under water-limited conditions. These insights hold significant practical value for breeding programs aiming to enhance chickpea productivity in drought-prone environments. By focusing on genotypes that combine stress tolerance with yield stability, the research contributes to the development of climate-smart chickpea cultivars essential for future food security in semi-arid regions.

AUTHOR CONTRIBUTION

Author	Contribution
Zulkaif Maqsood*	Substantial Contribution to study design, analysis, acquisition of Data Manuscript Writing Has given Final Approval of the version to be published
Khalid Hussain	Substantial Contribution to study design, acquisition and interpretation of Data Critical Review and Manuscript Writing Has given Final Approval of the version to be published
Muhammad Amir Amin	Substantial Contribution to acquisition and interpretation of Data Has given Final Approval of the version to be published
Ghulam Mustfa Siddiqui	Contributed to Data Collection and Analysis Has given Final Approval of the version to be published
Amer Hussain	Contributed to Data Collection and Analysis Has given Final Approval of the version to be published
Muhammad Irfan	Substantial Contribution to study design and Data Analysis Has given Final Approval of the version to be published
Javed Iqbal1	Contributed to study concept and Data collection Has given Final Approval of the version to be published
Asia Batool	Writing - Review & Editing, Assistance with Data Curation
Muhammad Tariq Mahmood	Writing - Review & Editing, Assistance with Data Curation
Ahsan Raza Awan	Writing - Review & Editing, Assistance with Data Curation

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