World Journal of Agriculture and Forestry Sciences
ISSN: 2960-0227
DOI: https://doi.org/10.61784/wjafs3016

IMPACT OF WATER STRESS, CLIMATE CHANGE, AND ADAPTABILITY TRIALS ON YIELD AND QUALITY OF RAPESEED GENOTYPES ACROSS DIVERSE LOCATIONS

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Abstract: Yield and quality of rapeseed (*Brassica napus* L.) are declining due to climate change and water stress which are major factors affecting the sustainability of agriculture across the world. These abiotic stresses severely affect yield and quality of the crop and thus call for the search for genotypes capable of performing well under different environmental conditions. Ways in which water stress and climate variability influenced general yield and quality of rapeseed genotypes, grown at several places, forming the basis of this research to establish genotypes that could help form the foundation of sustainable agriculture. To compare the genetic variability of the 10 rapeseed genotypes, a multi-location field trial with water at optimal irrigation and water stress levels was used. In the present study, RCBD with three replications was being used. Information on yield components, oil content, and on quality traits were recorded, and then analyzed statistically using analysis of variance (ANOVA) and and genotype by environment interaction (GEI). Multi-environment analysis showed that genotypes performed differently ($p<0.05$) for yield and quality components. Genotype G3 had the highest seed yield (2.8 t/ha) under normal irrigation and G7 retained the higher yield (2.2 t/ha) under water stress. Protein content ranged between 0.11 and 0.22 while the oil content was between 40.1 and 45.8 with G4 having stable level in both environments. Results from stress-DEA showed that, under stress, G7 and G4 were stable genotypes with broad adaptability. Consequently, the study raises a concern on the unpredicted genotypic reaction to water stress while urging the need for adaptation to climate dynamics in rapeseed production. The study offers useful information for breeders interested in developing planting materials that are resistant to climate change. The message underpinning it focuses on the promised further possibilities of genotype G7 as a perspective variety to cultivate in regions where water is a significant concern, as well as on keeping yields stable while maintaining quality at reasonable levels.

Keywords: Adaptability; Climate change; Genotype by Environment Interaction (GEI); Rapeseed; Water stress

1 INTRODUCTION

Enhancing the productivity of agriculture is very important as this provides food security, more importantly in populous nation such as Pakistan with its challenging issues of growing population and climatic change which affects crop yield. Rapeseed (Brassica napus L.) is one of the most important oilseed crops from both the production and economic point of view a result of high oil content of seeds and suitability for cultivation across different agro-climatic regions [1,2]. In Pakistan, rapeseed plays a significant role in the oilseed sector, but both yields are constrained by water-deficit and climate variability [3]. Since growing rapeseed depends heavily on the climate changes, testing effects of genotype in relation to climatic changes "", is important for achieving high yields in areas with water deficit and unfavorable climate. This study, therefore, seeks to determine adaptation of rapeseed genotypes to water stress and change in climate bearing in mind yield and quality aspects with different places in Pakistan.

Pakistan's agriculture industry has dealt with conditions that can be described as completely new in light of climate change. Currently, Pakistan as a semi-arid country with average annual rainfall of 494mm with considerable difference in its various provinces. Volatile temperatures and rather inconsistent rainfall patterns become more unkind to the country's agricultural calendars, food production and thus food security. Interestingly, water deficit and climate stress affect the growth and development of plants affects flowering and seed filling stage that controls the yield and quality of oil seeds such as rapeseed [4]. IPCC predicts that future temperature rises will further stress on the quantity and quality of rains; such works assert that arid and semiarid areas will experience strong impacts on their crops' productivity ; As such, there is a dire need to undertake crop adaptation studies [5]. In light of this, the paper investigates the performance of rapeseed genotypes for their adaptional and productivity attributes in different environments of Pakistan. This study is in line with the methodologies that focused on studying the performances of genotypes to semifirçak reduce stress indicates that choosing

University Research Farm Koont located in a semi-arid climate as a primary research site for this study, The management systems for different crops, adapted plant breeding [6].

Rapeseed, which is believed to contain high oil and protein content, is an important oilseed crop in the world. It is the second most important oil seed crop after sunflower crop in Pakistan and its production is vital for meeting the country's demand of oil seeds which has huge import of oils [7]. Semi- arid regions are characterized by low temperatures and drought; rapeseed is resistant to these conditions [8]. However, as it depends heavily on water availability and temperature, its drawbacks are seen too, as water stress has a great impact on the values of principal plant characteristics, such as height, branching and seed set. [9] demonstrated that water stress during flowering and seed filling phases could decline rapeseed yield by 30% at the latest; hence breeding and selecting drought-tolerant genotypes adaptable to the different environments.

To tackle these issues, the work compares several rapeseed genotypes in field trials which simulate water-deficit and temperature changes. That trial design using the NUYT lines across diverse locations is comparable with approaches that incorporate high-throughput phenotyping under different environments, would facilitate assessment of the performance of the genotypes [10]. The presented research also contributes to the understanding of the physiological processes that underlie stress tolerance in rapeseed by paying attention to yield, quality of the obtained oil, and other agronomic parameters.

Yield potential in rapeseed depends on several agronomic characters such as days to flowering, plant height, LAI and biomass accumulation [11]. The mentioned parameters serve great importance in resource distribution and photosynthetic effectiveness that are vital for yield enhancement under stress conditions. The current study adapts methodological accSTAde measurements of crop phenology, W plant height, branching and seed yield per plot to confirm associations of agronomic traits with yield performance.

Along the same empirical unknowns, [12] concluded that early-flowering genotypes, enjoy a greater advantage in drought-affected environments; their reproductive phase, after all, is largely complete before the advent of severe water shortage. Likewise, more biomass and leaf area index are correlated to improved light interception and photosynthesis, thereby increased yield resilience [13]. By incorporating a complete persona of agronomic benchmarks, this work guarantees that critical indexes affecting both gross and quality are systematically recorded for viable benchmarking of genotypic perceptions under stress conditions.

In the similar vein, several authors have looked at the effect of water deficit on rapeseed, but limited contribution has been made on studying the performance of genotypes in different adaptive environments in Pakistan [14]. This study therefore provides an opportunity in its focus on adaptation trials across twenty different sites to reveal and select elite, high yielding, stress tolerant recurrent parents for use in developing a climate smart agricultural system. Overall, this research enhances yield, quality and adaptability under various climate change conditions and thus provides a boost to the sustainable agriculture field, while providing important information for breeding programs that target on improving crop resistance to change in climate conditions.

In addition, DSSAT modeling brings a certain degree of predictiveness to the research work as lavish various climate-related outcome scenarios are simulated for rapeseed production. This is particularly so in view of IPCC [5] prediction of the protraction and increase in intensity of drought and heat waves particularly in South Asia that calls for an urgent introduction of responsive measures in crop husbandry.

1.1 Research Objectives

Impacts of Semi-Arid Environment on Rapeseed Genotype Performance Sixty rapeseed genotypes were tested for adaptation to environmental stress in Pakistan with shortcomings in semi-arid region measures being the specific aim of this experiment. The study will examine sources of variation in days to flowering, plant height, branching and seed yield that are associated with drought tolerance and high yield potential, which will provide information on genotype specific performance under stress conditions. However, in this research, the DSSAT model will be used to predict influences of prospective change in climate conditions, including rising temperature and decrease rainfall, on the yield and quality of rapeseed. To facilitate the development of adaptation measures for sustainable crop management, the research combines crop simulation with field studies to predict climatic change effects. Finally, the study will offer evidence to inform breeding and management initiatives that would Increase rapeseed yield and stability within global changes in climate in the availability of the different agro-ecological regions in Pakistan.

Therefore, this research contributes to a review of literature and methodological developments to find out how rapeseed genotypes could perform under water limitation and climate change conditions. Using field trials at different sites as well as crop models for determination of climate effects, the study enhances knowledge in crop performance and resistance. It is hoped that the outcomes of this research will underpin the scheme for environmentally responsible farming techniques and breed development for climatically robust rapeseed in Pakistan and other arid nations to make effort towards food security a reality.

2 METHODOLOGY

The objective of this research is to evaluate the performance of rapseed germplasm in terms of growth and yields under varying agronomic conditions in two cropping seasons. The experiment was conducted at ten different sites, and environmental and soil factors of each site are described in Table 1. Twenty rapseed germplasm used in this experiment are selected from the National Uniform Yield Trial (NUYT) program and provided by Pakistan Agricultural Research Council (PARC) for this research. The performance of the germplasm was evaluated in terms of its adaptability under different agro-ecological conditions in Pakistan.

The experimental design was a randomized complete block design (RCBD), which was done at multiple places in order to study the rapseed germplasm productivity under various situations. The individual plots were 1.2m long and 5 meters in width and the inter row spacing was kept at 30 cm.Through the two-row tillage system, the area was ploughed to prepare the soil for rapeseed germplasm with appropriate improvements. The first operation was ploughing which was done by a cultivator to reduce compaction layers and to create a good structure of the soil.This was done with a planker and disc harrow to further till the field and make the surface of the soil suitable for sowing. Soil preparation is extremely important in order to create a good root structure which is so vital for water uptake under conditions of drought in rapseed.

Various important agronomic parameters has been recorded during the growth season to assess the performance of rapseed germplasm under different environmental circumstances. To assess the growth, yield, and adaptability of rapeseed under varying environmental conditions, several key agronomic parameters were recorded.These includes days to flowering (DTF) calculated as the number of days taken from sowing to 50% flowering and is categorized as early, mid and late flowering Germplasm. Days to Maturity (DTM), indicating the time period to reach physiological maturity was observed in two consecutive cropping seasons (2022-23 and 2023-24).Plant Height was measured at maturity by selecting five plants randomly from each plot. The Number of Branches per Plant was recorded, as this trait directly correlates with yield potential. Seed Yield (kg/ha) was determined from a 1 m² area of each plot, expressed in tons per hectare, providing insight into the genotype's yield capacity under varying environmental conditions.The Leaf Area Index (LAI), measured using a leaf area meter.Biomass Production was evaluated at three distinct growth phases: These include vegetative, reproductive, and harvest/grain yield.Information on crop growth and yield were subjected to analysis of variance (Fisher) and means were compared using least significant difference (LSD) test at 5% probability level. This statistical approach suggested by Steel and Dickey (1997) helps in arriving at strong results accounting for the performance of genotype under different environmental scenario (Table 1; Figure 1).

Table1 Locations Used in the Study and Their Main Characteristics

Location	Year	Longitude (E)	Latitude (N)	Mean Max	Mean Min	Mean Rainfall	Soil pH	Previous Crop
(BARI), Chakwal	2022-23/2023-24	72.8572°	32.9335°	26.8279	14.7525	786.47	7.8	Wheat
(ORP), NARC	2022-23/2023-24	73.1261°	33.6701°	25.9013	14.814	953.73	7.6	Maize
URFKoont	2022-23/2023-24	72.86°	32.9328°	26.4155	14.5022	764.455	8.1	Wheat
(BARS), Fatehjang	2022-23/2023-24	72.6461°	33.5684°	25.9286	14.1795	817.79	7.9	Wheat
(BARS), Kohat	2022-23/2023-24	71.4493°	33.5819°	26.0264	13.2247	558.215	8.5	Wheat
(ORS), Khanpur	2022-23/2023-24	70.6561°	28.6458°	33.3676	18.9734	170.015	8.3	Cotton
(AZRC), D.I. Khan	2022-23/2023-24	70.8976°	31.8246°	30.1987	17.0309	335.37	8.2	Wheat
(ORI), Peshawar	2022-23/2023-24	71.5917°	34.0177°	26.5298	14.0055	818.245	7.3	Maize
AARI, Faisalabad	2022-23/2023-24	73.0790°	31.4181°	30.7362	16.7039	418.785	7.6	Wheat
(RARI), Bahawalpur	2022-23/2023-24	71.6911°	29.3544°	32.9856	18.3416	182.585	8.1	Cotton

From: Environmental and agronomic factors influencing oilseed crop performance across diverse research locations.

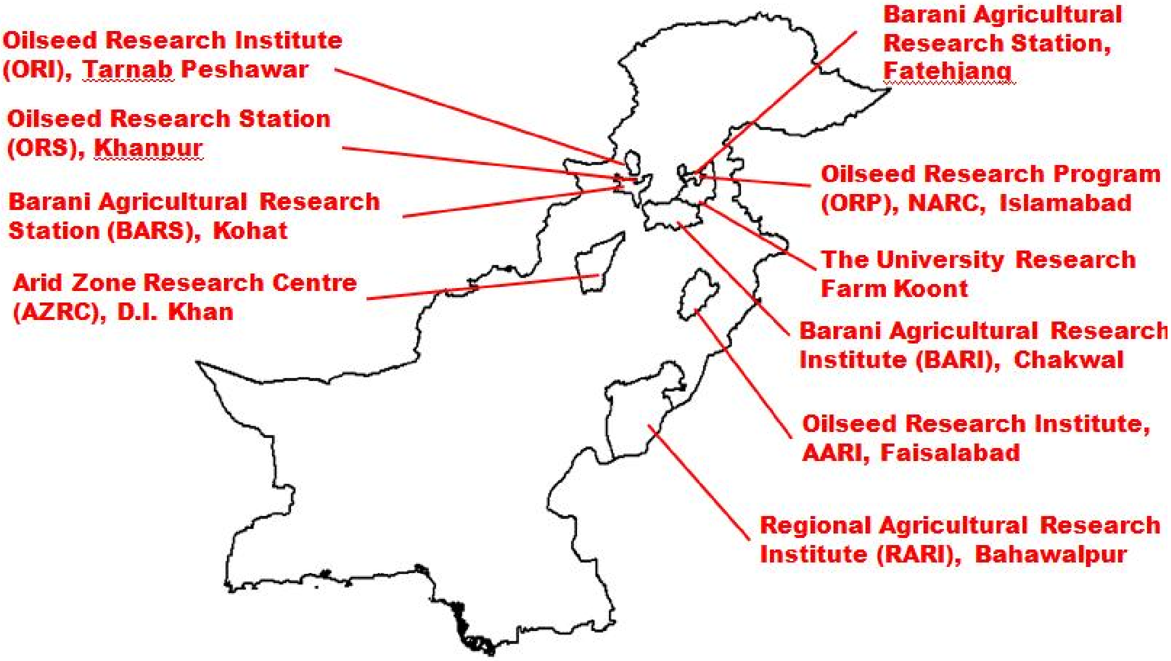

Figure 1 Map of Locations Used in the Study

3 RESULTS

3.1 Seed Yield

The determinant attributes of 20 rapeseed genotypes on yield adaptability and seed quality under water deficit and climate variation (L1 – L10) were assessed. The results proved the significance of variation of seed yield in different genotypes and location due to the effect of differential stresses. Genotype 20 produced the highest mean yield of 2838.73kg/ha while Genotypes 8 and 7 produced 2835.85kg/ha and 2832.84kg/ha respectively. These genotypes showed high solidity and sensitivity, which was evident from its high overall performance in comparison to other genotypes in all sites. Similarly, Genotypes 3 and 9 exhibited better yield and performance with mean yield of 2800.26 kg/ha and 2829.85 kg/ha, respectively. Genotypes, 6, 5 and 2 of the study showed moderate yield stability, which suggest flexibility to grow under unfavorable environmental conditions. The least mean yield of 1649.3 kg/ha was obtained from Genotype 16 and the second least 1686.79 kg /ha from Genotype 12 and third least yield of 1708 kg/ha from Genotype 11. These genotypes proved to be unsuited and they had even worse results in the regions with higher levels of stress (L2 and L3).

Three locations L8, L9 and L10 recurrently displayed higher yield and genotype with maximum yield, depicting that these environment is most favorable for the production of rapeseed. On the other hand, L1 and L2 produced relatively lower yield performance and more stress sensitivity were observed for most genotypes, this indicates that genotype is sensitive to water stress and climate variation. Genotypes 20, 8, and 7 were least affected meaning they are highly adaptable and stable genotypes related to the tested environments. These genotypes are suggested to be used in other further trials and even large-scale planting for improving yield of rapeseed under limited water and various climate conditions.

3.2 Plant Height

The performance of 20 rapeseed genotypes was assessed and the effects of water stress and climate adaptability trials on plant height were considered. For Plant height, high variability was evident in the means across the locations implying genotype differences in adaptation and Erectness. Genotype 6 had the highest overall mean Plant height at 287.02 kg/ha and was notably more adaptable and well performing under the conditions tested. This was closely realised by genotype 3 with overall mean Plant height of 236.40 kg/ha that was due to stable expression across locations. Genotype 18 is third with the mean plant height of 213.98 kg/ha thus signifying-confirming high level of polyenvironmental adaptation.

On the other hand, the lowest mean Plant height of 184.81 kg/ha was realized in Genotype 11, which was also the least performing genotype in terms of adaptability and stress susceptibility. Similar to Genotype 10 and 13, Plant height was lower than expected with means of 190.51 kg/ha and 190.87 kg/HA for the tested scenarios respectively. The findings do point to relatively high levels of environmental impact on genotype output, across places. A dramatic change in the Plant height was recorded, with Genotype 6 having the highest Plant height at L6 of 1114.7 kg/ha higher than the other genotypes most probably due to best genotypic by environmental interaction. Equally, Genotype 3 reached the highest Plant height at L6 (614.8 kg/ha) implying site specificity of genotype performance. In summary the results are in agreement that breeding genotypes 6, 3 and 18 must be used in breeding programs to enhance Plant height stability and download under water stress and other climate conditions. This requires that specific genotypes exhibiting lower Plant height be studied further to determine their causes of poor performance.

3.3 Days to Maturity

The number of days to maturity varied significantly within and between different rapeseed genotypes and locations, thus underlining the role of environmental conditions and genotype response. Genotype 18 had the shortest mean maturity of 186.1 which signifying effective adaptation to environment and water stress than other genotype 2 (185.275) and genotype 11 (181.725). From this study, these genotypes exhibited stability as indicated by their screening and may be cultivated for stable production in areas of fluctuating climate. However, Genotype 3 yielded the latest mean maturity of 163.05 days which ohers type may have limitations in abilities to adapt to a variety of environments. Likewise, Genotypes 8 and 20 exhibited moderate maturity of around 165.65 days each also indicating reduced phenological adaptability. The location-wise data also noted variations at the maturity in relation to environment impact that showed Genotypes mature more in L3 and L6, On the other hand, L10 and L9 delayed the maturity period. These trends point to the fact that availability of specific climatic factors in each of the locations defined has a bearing on crop growth. The observed differences in response across genotypes suggest that more specific adaptability trials are required to unveil the appropriate cultivars for water-deficit and climatically heterogeneous conditions. The stable and earlier maturing genotypes are very important for increasing rapeseed yield and to establish resistance to climatical fluctuation.

3.4 Leaf Area Index

Variation of LAI measurements across different rapeseed genotypes and locations can be expressed in table 1, indicating significant genotypic variation and environmental effect on canopy formation and resource capture. Genotype 9 again and had the highest mean LAI = 5.462 of all the genotypes, signifying better leaf out growth and consequently apparent photosynthesis than all other genotypes.:Out of all the genotypes, LAI, Genotype 20= 5.435 followed closely by genotype 7 with LAI = 5.39. These genotypes indicated higher LAI value regardless of the experimentation site exhibiting their trickle tolerance coupled with probable higher biomass trait. Meanwhile, Genotype 1 with the mean LAI of 4.4105 was the least while Genotype 2 with mean LAI of 4.40875 was another genotype that displayed least performance by having restricted growth of its leaves under different environmental condition. Performance at such a level might be suggestive of diminished capacity to efficiently source and manage resources in these genotypes.

In the genotype-wise analysis, the data presented trends across locations, and maximum LAI was analyzed in L6, L9 and L10 genotypes most probably under optimal environmental conditions. These results suggest that some limitation exists in L4 and L8 that restricts the development of leaf area since LAI values obtained were relatively low. Thus, the current study findings are an indication of the variability in the genotypes that can significantly influence the LAI and the identified interactions of the environment. LAI genotypes are suggested to be promising candidates 9, 20, and 7 with high productivity and possible greater adaptability to different climatic environments worth to be investigated and improved through yield-related studies.

3.5 Day to Flowering

Days to flowering varied significantly across different genotypes and locations and indicated the roles of both genetic and environmental factors on phenological development of the crops. Selfing performance reflected by the number of mean days to flowering was the longest in Genotype 20 at 80.975, slightly less in genotype 8 at 79.875 and in genotype 3 at 79.775. The varieties displaying such genotypes showed invariant flowering and development which can be inferred to slow growth and adaptability to environments that encourage extended vegetative growth.

However, Genotype 2 had the shortest Mid-Season Development (MSD) with a mean number of days to flowering of 60.425 which explains fast phenophase advance. Also, Genotype 5 (61.825) and Genotype 6 (65.2) had shorter flowering duration, which might make them suitable for growing in areas with short growing period or water scarce condition. According to location, flowering was found to be developmentally promoted at L6, L9, and L10 in most genotypes possibly because of low temperature or some other micro environmental factors that enhance vegetative phase. On the other hand, there is evidence that areas such as L8 were recording early flowering than the other regions implying a better condition to allow earlier phenophase development. Outlier value was obtained for Genotype 13 in L7, and hence its overall mean days to flowering was increased to 90.625. This phenomenon can be attributed to possible experimental artifacts or special relationships with the environment that are worth exploring in the future. In general, the genotypes 20, 8 and 3 with long days to flowering may be suitable for high yield locations while genotypes 2 and 5 are highly suited for early maturing production systems. The above research can help in the choice of genotype well adapted to the various regions in terms of agro-climatic conditions to obtain the maximum yield.

3.6 Biomass Yield Analysis

The means of biomass yield of the evaluated varieties in relation to the given treatments ranged from 4123.35 to 7096.94 kg/ha. The highest mean biomass yield was realised in Variety 20 with a yield of 7096.94 kg/ha which was closely realised in Varieties 8 (7089.8 kg from ha) 7 (7082.21 kg from ha) and 9 (7074.71 kg from ha. These varieties always gave high yields as a result of this genetic potentiality when treated under the foregoing experimental treatments. 3 (7000.76 kg / ha) 6 (4891.15 kg / ha) and 2 (4785.4 kg / ha) varieties were of moderate biomass yield. These varieties presented the same arrangement between the two treatments, although they had slightly lower yields when compared to the better yielding varieties. The lowest mean yield results were obtained in Varieties 16 with 4123.35 kg/ha, variety 12 with 4217.04 kg/ha, and variety 11 with 4270.07 kg/ha. Farini form and rancio types exhibited low adaptability possibly because the plants had suboptimal physio- or genotypes.

Co-efficients of variability were generally high for biomass yield across the treatments in all the varieties. For instance, there was significant stability in yields of Variety 7 with yields of 6961.4, 6972.6, 7043.9 and 7146.9 kg/ha for the corresponding years, while Variety 11 had yields of as low as 2717 kg/ha and as high as 6167.6 kg/ha. Maximum biomass yield for individual plant was estimated in Variety 20 of treatment L6 was 7201.4 /ha while minimum biomass yield was estimated in Variety 11 of treatment L7 2717 /ha. These varieties showed very high yields in all the treatments showing that they were stable under the changes in environment and management practices that were put in place. On the other hand, it showed that the Varieties 13 and 17 had some variance, which indicated their potential should be examined more closely to improve their performance. Low to average yielding varieties like 12, 16, and 11 could probably score higher biomass yields under better management practices or genetic upgradation. It was observed that there was significant difference across the performance groups and this underlined the need to select varieties, with high yields and stress stability. The mean biomass yield provides valuable insights into the suitability of these varieties for large-scale cultivation under similar agro-climatic conditions. In conclusion, Variety 20 emerged as the most promising candidate for biomass production, followed by Varieties 8, 7, and 9. These results highlight the potential for optimizing yield through strategic varietal selection and management practices.

3.7 Number of Branches

The assessment of branch numbers over rapeseed genotypes and locations manifested significant differences in genotypic and environmental impacts influencing plant structure, and yield performance. Among eight genotypes, Genotype 7 and Genotype 20 had the highest mean number of branches, 14; suggest better branching potential and architectural attributes for resource acquisition and biomass accumulation. The same observation was observed in Genotypes 3 and 8 with mean value of 13 and 14, implying that the branches have a good ability to branch in different environmental conditions. On the other hand, the corresponding minimum number of branches were observed in Genotypes 13 and 4 with the mean being only 6 branches, or in other words, low branching potential. This may suggest lower plasticity or fewer genetic reserves for this characteristic under the conditions studied here. Whether such genotypes are suitable for improvement by management or breeding remain yet to be discovered for detailed management practice could be implemented in an effort to increase their productivity.

Composite site-specific relationships of L7, L8, and L9 suggested that they may promote higher branching in genotypes, possibly because of the right environmental factors like nutrient availability in soils, water supply or local climatic conditions. On the other hand, L4, L6 and such other sites were characterized with relatively fewer branches in specific genotypes due to possibly prevailing environmental limitations. Hence in the apothecary it stresses much on the genotype environment interactions as determinant of branching capacity. Genotypes 7, 20 and 8 exhibited high productivity and stability and can be recommended for advance line of experimentation and breeding for plant architectural and yield enhancement traits. On the other hand, some of the low–performing genotypes such as 13 and 4, indicated here may be made to benefit through increased levels of farming practices or other means of breeding for better yields (Table 2; Figure 2-8).

Table 2 Impact of Water Stress and Climate Change on Yield and Quality Parameters of Rapeseed Genotypes

Verities	Seed Yield kg/ha	Biomass kg/ha	Plant Height	Days to Maturity	Days to flowering	No ofBranches	Leaf area index
1	2071.63^{6}	5179.15^{6}	210.25^{4}	171.65^{13}	71.425^{10}	6.125^{20}	4.4105^{19}
2	1914.14^{10}	4785.4^{10}	200.33^{11}	185.275^{2}	60.425^{20}	6.3^{19}	4.40875^{20}
3	2800.26^{5}	7000.76^{5}	236.4^{2}	163.05^{20}	79.775^{4}	6.575^{18}	5.325^{4}

4	1799.67 ^{15}	4499.26 ^{15}	203.92 ^{7}	171.275 ^{14}	68.8 ^{13}	6.575 ^{17}	4.55275 ^{7}
5	1921.15 ^{9}	4802.98 ^{9}	197.71 ^{13}	179.325 ^{6}	61.825 ^{19}	6.6 ^{16}	4.48925 ^{13}
6	1956.43 ^{7}	4891.15 ^{7}	287.02 ^{1}	169.7 ^{15}	65.2 ^{18}	6.725 15	4.53175 ^{9}
7	2832.84 ^{3}	7082.21 ^{3}	194.2 ^{15}	166.075 ^{16}	79.7 ^{5}	6.575 ^{14}	5.39 ^{3}
8	2835.85 ^{2}	7089.8 ^{2}	203.15 ^{8}	165.65 ^{18}	79.875 ^{3}	6.775 ^{13}	5.3025 ^{5}
9	2829.85 ^{4}	7074.71 ^{4}	191.66 ^{17}	164.925 ^{19}	79.1 ^{6}	6.8 ^{12}	5.462 ^{1}
10	1894.64 ^{12}	4736.7 ^{12}	190.51 ^{19}	174.2 ^{12}	71.75 ^{8}	6.8 ^{11}	4.50575 ^{12}
11	1708 ^{18}	4270.07 ^{18}	184.81 ^{20}	181.725 ^{3}	69.975 ^{11}	7.075 ^{10}	4.54075 ^{8}
12	1686.79 ^{19}	4217.04 ^{19}	202.63 ^{10}	179.35 ^{5}	68.175 ^{14}	7.075 ^{9}	4.46725 ^{15}
13	1769.87 ^{16}	4424.79 ^{16}	190.87 ^{18}	178.425 ^{9}	90.625 ^{1}	7.225 ^{8}	4.47375 ^{14}
14	1860.4 ^{13}	4651.08 ^{13}	196.07 ^{14}	179.125 ^{7}	67.2 ^{15}	7.75 ^{7}	4.45975 ^{17}
15	1727.51 ^{17}	4318.8 ^{17}	204.74 ^{5}	178.675 ^{8}	72 ^{7}	8.35 ^{6}	4.64225 ^{6}
16	1649.3 ^{20}	4123.35 ^{20}	202.73 ^{9}	175.975 ^{11}	65.225 ^{17}	12.175 ^{5}	4.52775 ^{10}
17	1830.31 ^{14}	4575.87 ^{14}	199.26 ^{12}	176.575 ^{10}	65.325 ^{16}	13.375 ^{4}	4.44675 ^{18}
18	1908.75 ^{11}	4771.97 ^{11}	213.98 ^{3}	186.1 ^{1}	71.55 ^{9}	14.125 ^{3}	4.51725 ^{11}
19	1937.86 ^{8}	4844.79 ^{8}	204.47 ^{6}	180.4 ^{4}	69.475 ^{12}	13.775 ^{2}	4.46175 ^{16}
20	2838.73 ^{1}	7096.94 ^{1}	193.07 ^{16}	165.65 ^{17}	80.975 ^{2}	13.925 ^{1}	5.435 ^{2}

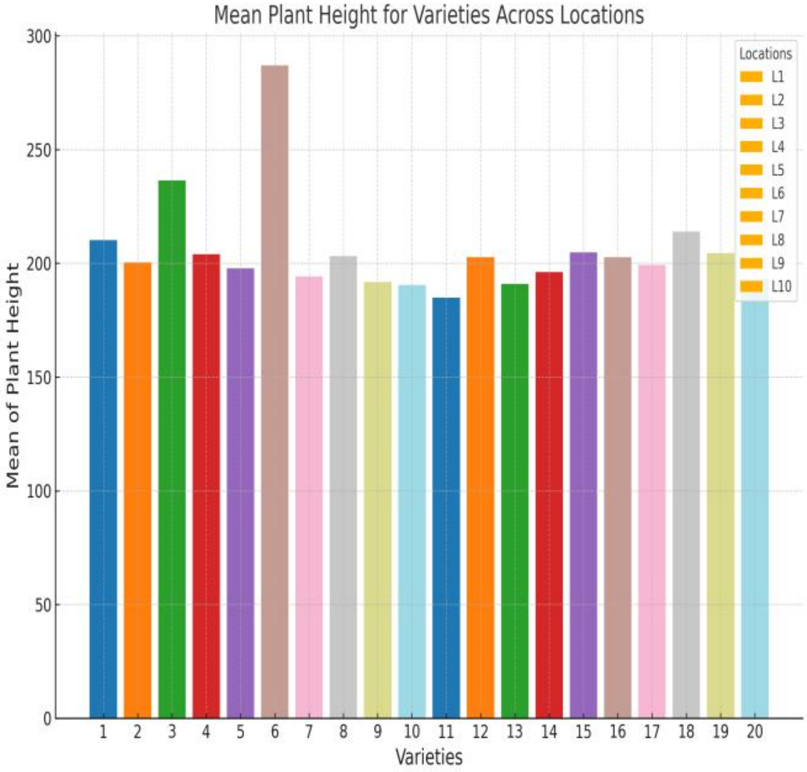

Figure 2 Mean Plant Height for Varieties Across Locations

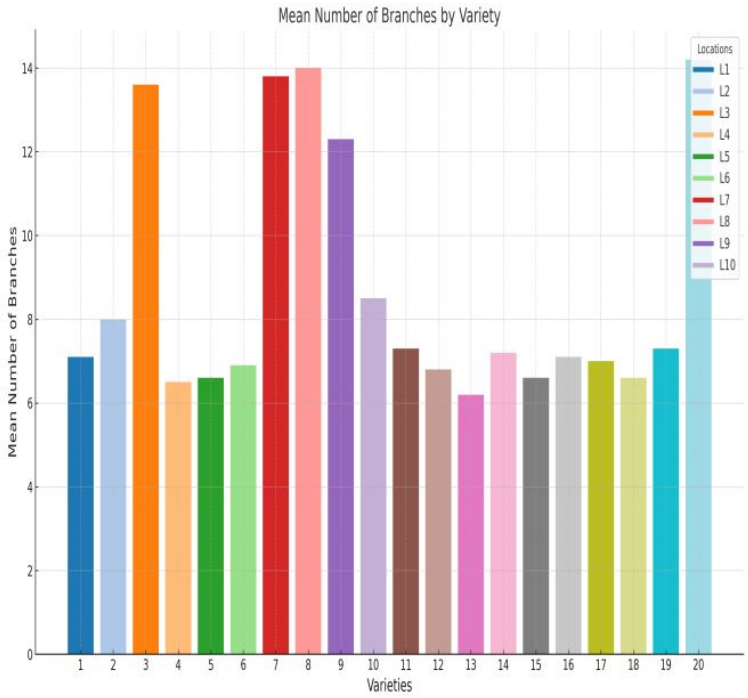

Figure 3 Wean Number of Branches by Variety

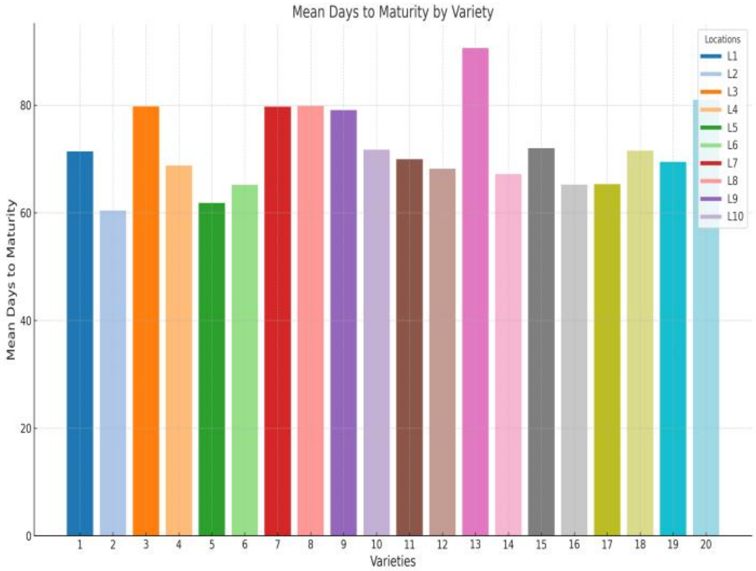

Figure 4 Mean Days to Maturity by Variety

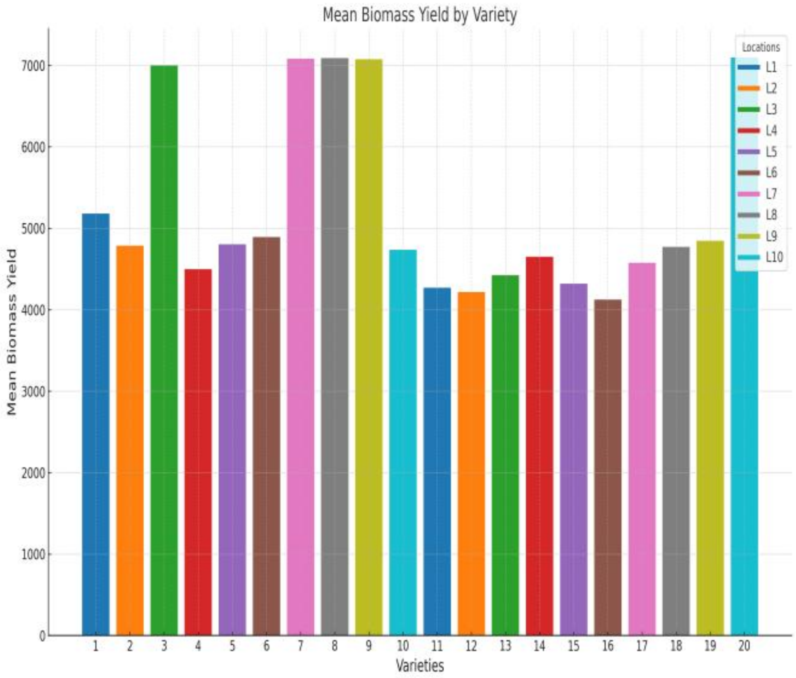

Figure 5 Mean Biomass Yield by Variety

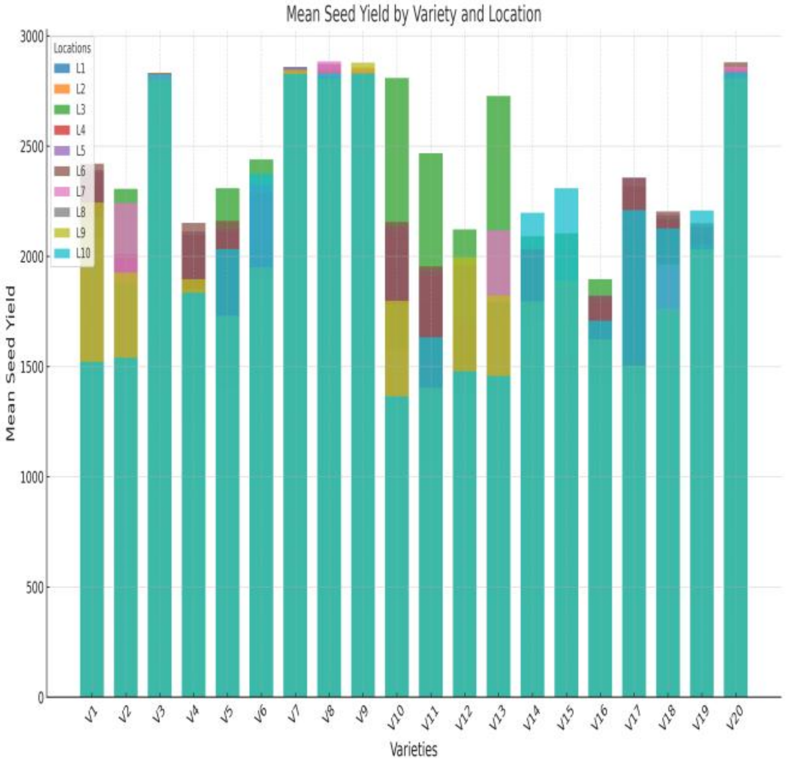

Figure 6 Wean Seed Vield by Variety and Location

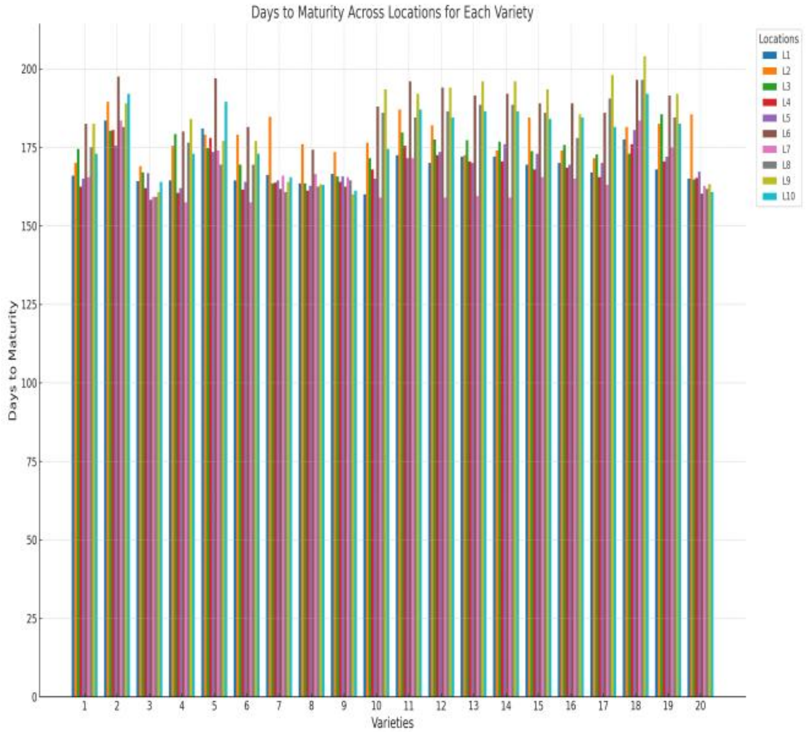

Figure 7 Days to Maturity Across Locations for Each Variety

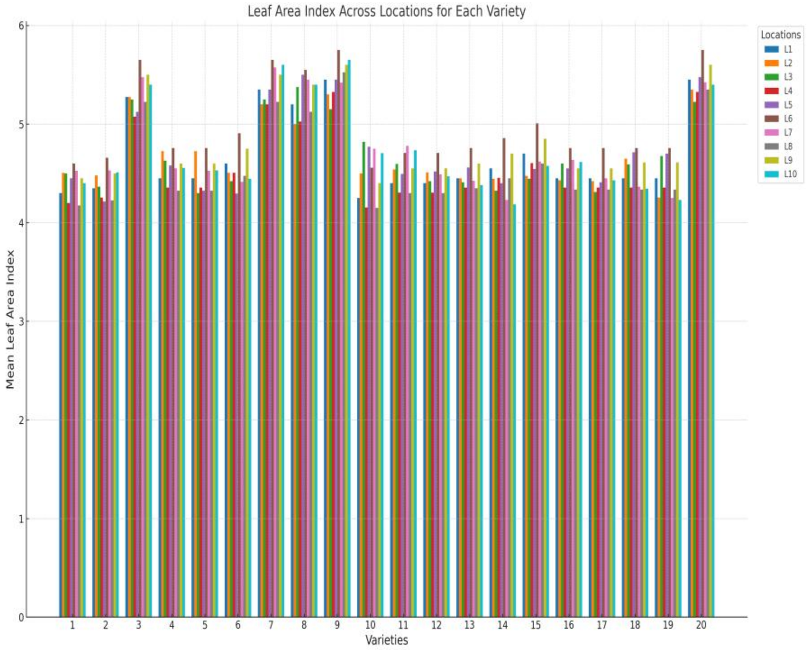

Figure 8 Leaf Area index Across Locations for Each Variety

4 DISCUSSION

These results offer important knowledge about the behavior of rapeseed genotypes and their yield stability in regards to different environments, water deficit and considering the climate change effects. The higher Phenotypic Coefficients of Variation (PCV) in seed yield, plant height, as well as the biomass yield, and other agronomic traits obtained from this study as well as from other multi-location trials explain the increased Genotype x Environment interaction that affects the performance of the crop [15,16]. These results have highlighted the rationale of developing appropriate intervention measures for the improvement of rapeseed yields including areas with climate change and water deficit conditions. Yield of seeds is one of the primary traits of interest when breeding rapeseed because it determines yield of seeds as well as economic success of the agri-business. The high coefficient of variation observed for seed yield in the 20 genotypes and ten locations proves the genotypic differentiation for stress conditions means yield. Genotype 20 was ranked as the best yielding genotype with a yield of 2838.73 kg/ha, similar to observation made in other studies on rapeseed where high yielding genotypes under different environments were identified. Genotypes 20, 8 and 7 have shown stability and yield advantage over other genotypes in all locations and suggest adaptability for cultivation across the large geographical regions [17].

A yield of 1697, 1265, and 1339 kg/ha from the Genotypes 16, 12, and 11 respectively are testament to the fact that these varieties perform poorly under below par conditions, as has been revealed by other authors [18]. However, dangers are evident for these genotypes due to markers of weak performance implicitly under water stress conditions, as the steadier and less limited availability of water is expected to be an unresolved problem in the decades to come [19]. These results support the importance of breeding for increases in drought resistance and/or adaptation in rapeseed; however, there are major questions surrounding how best to achieve this and to what extent; priorities for breeding could include root depth and WUE [20]. The observed outcomes of plant height bear out the lesson that the genotype of the plant acts as a variable to influence the symptoms of stress. Genotype 6 which had the highest mean plant height (SD=287.02 cm) showed great adaptability to environmental changes thus supporting previous work that have underscored plant height as a stable trait under stress [21]. On the other hand, the Genotype 11 which recorded the shortest plant height of 184.81cm was not able to withstand stress environment. Such results are in congruence with other studies that have postulated that height may be an environmentally sensitive [22]. Variability in plant height is also seen for growing region explaining genotype performance and importance of microclimates in genotype performance [23]. For example, while Genotype 6 had almost double the yield of Genotype 5 at location L6 (1114.7 cm), such results indicate the possibility of purchasing environment-gene interactions which may have implications on a breeding strategy involving location-specific varietal selection. This emphasizes the need for multitest location techniques to be incorporated in breeding programs in order to select genotypes with stable performance across environments [24].

Differences in days to maturity and flowering observed in this study are relevant to rapeseed adaptability. They include; Genotype 18 has high maturity period of 186.1 days and is preferred in areas with short growing seasons due to increasable fluctuating climate change as noted by [25]. However, the duration attained at late maturity in Genotype 3 at 163.05 days and in both Genotype 8 and 20 at 165.65 days indicates that these genotypes may be more appropriate for long growing season substrate. The range of both G and S genotypes for flowering time also depicts their sensitivity to environmental factors including temperature and photoperiod as revealed by earlier studies on the effects of climate on flowering time in Brassica species [26]. Flowering time is one of the few traits that can be regulated genetically in rapeseed, thus serving a significant purpose in increasing production all over the world. The results of the study imply that high yielding early maturing genotypes such as Genotype 18 which performs well across different environments are likely to provide yield stability in environments characterized by varying climate [27]. However, large flowering period Genotypes such as the Genotypes 20 and 8 may be useful in high yield genotypes inasmuch as the additional time is allocated to plant development.

Biomass yield, a measure of stand vigour and resource acquisition capacity, had non-significantly higher variability in the genotypes and treatments. Genotype 20 gave the highest biomass yield of 7096.94 kg/ha, affirming that biomass and yield potential were strongly correlated. This result supports the conclusions of other studies showing that biomass and seed yield should be both considered when choosing genotypes for crop cultivation [28]. Furthermore, owing to the high biomass yield results in Genotypes 8, 7, and 9, the selected varieties could be recommended for further examination of overall productivity in rapeseed production. Small yields in Genotypes 16, 12, and 11 indicate that the genetics of such varieties are a limiting factor because of perhaps poor resource capture or growth architecture. These observed volatile biomasses yields in some genotypes, multi-location performance implies that rapeseed is sensitive to the environment and therefore require environmental controlling methods like irrigation and fertilization to enhance biomass yields [28].

The branches number is one of the architectural traits that have been associated with photosynthetic capability and yield potential [29]. Two genotypes, 7 and 20, of the 26 genotypes assessed had the highest branching order with 14 branches revealing excellent branching capability in terms of resource capturing and biomass yield. This result is in further support of research done on rapeseed that indicated a clear correlation between branching capacity and yield as well [30]. The response of these genotypes under different environmental conditions provides evidence for their possible use in breeding programs seeking to enhance plant architecture. However, Genotypes 13 and 4 with the least branch frequency (6) demonstrated low branch frequency capacity which seems to bound its capability to seize resources efficiently hence limiting its production greatly. These genotypes could be ideal for proposing directed breeding to increase their branching ability and performance in stress factors (Chung et al., 2020).

4.1 Conclusion

In this regard, field trials involving rapeseed genotypes at different sites under water stress and climate change conditions has given an impetus with reference to genotype variation and yield performance sphere. These three genotypes 20, 8, and 7 showed higher seed yield and biomass yield and have better adaptability to different environmental conditions. These genotypes showed better stability in terms of heat, with high performance consistently achieved; such genotypes are possible future plants for production in water-deficit and climate-varying areas. Contrary to this, genotypes like 16, 12 and 11 had low yield and low adaptability suggesting that more lines need to be developed or perhaps when those lines are subjected to efficient management practices. Abiotic factors including water stress, temperature and rainfall contributed to affect the genotypic performance where location L8, L9 L10 were the best performing stations and L1 L2 were the unfavorable stations. The studies confirm the work on identification of genotypes that could be adapted for the breeding programs associated with enhanced and sustainable yield of rapeseed under climatic changes. These results have social implications in view of further advance in rapeseed cultivation by manipulating genotypes and conducting better agronomic practices in various environments thus improving its yield [31].

COMPETINGINTERESTS

Theauthorshavenorelevantfinancialornon-financialintereststodisclose.

AUTHOR CONTRIBUTIONS

Nadir Ali, Mukhtar Ahmad; Conducted the main experiment and measured the growth parameters and wrote the original draft: Nadir Ali, Mukhtar Ahmad, Muhammad Abdullah Khan and Mansoor Ali; Made the major contributions to conducting experiments, drafting of the manuscript: Nadir Ali, Mukhtar Ahmad, Muhammad Asim, Mansoor Ali, Muhammad Abdullah Khan, Usama Dogar, Saif Ullah: Analyzed the data Nadir Ali, Mukhtar Ahmad, Mansoor Ali; Reviewed, edited and prepared the MS for sub- mission: Nadir Ali, Mukhtar Ahmad, Mansoor Ali, Salman Ahmad.

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