IDENTIFICATION OF CLIMATE RESILIENT HOT PEPPER (*CAPSICUM ANNUM L.*) GENOTYPE FOR DEVELOPMENT OF HIGH YIELDING CULTIVARS

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Abstract

Climate change present a formidable challenge to the cultivation of hot pepper *(Capsicum annum L.)*, profoundly impacting not only vegetative growth but also leading to flower and fruit abscission, thereby causing a significant reduction in yield. An experiment was conducted at Vegetable Research Institute Faisalabad to identify climate resilient genotype. Ten different genotypes was evaluate at two different date of sowing normal and late with difference of one month. The Results indicated that genotype VRIHP006 had highest plant height, primary branches, leaf length, leaf width, canopy temperature, NDVI value, chlorophyll contents which supports to produce high number of fruits yield per plant, average fruit weight and 100 seed weight. The studies indicated that selection of genotypes under climate stress environment for morphological and physiological traits can help in developing high yielding genotypes. The genotypes VRIHP006 and VRIHP004 can be used in further breeding program.

Introduction

The hot pepper, a vibrant and piquant staple of culinary traditions worldwide, is a member of the diverse Solanaceae or nightshade family. This family includes a variety of species that are integral to diets across the globe. The genesis of the hot pepper can be traced back to the Capsicum annum var. minimum, a wild and weedy progenitor native to the rich and varied landscapes of Mexico, southern Peru, and Bolivia in Latin America (Villalon, 1981). This particular variety of Capsicum is characterized by its diploid nature, possessing a chromosome count of 2n=2x=24, which equates to 12 pairs of chromosomes. The genome of this species is expansive, approximately 3.5 gigabases in size, with a significant portion, about 75 to 80%, comprising repetitive DNA sequences, which play a crucial role in the structure and evolution of the genome (Saisupriya and Saidaiah, 2021). Hot pepper is a crop of significant economic importance globally. It is cultivated extensively across various continents, with countries like India, China, Thailand, and Mexico being some of the leading producers (Chilli outlook, 2021). The production of hot pepper is influenced by a myriad of factors, including climatic conditions, soil fertility, and the prevalence of diseases and pests. In recent years, climate change has emerged as a formidable challenge, impacting hot pepper production adversely (Jha *et al*., 2014). Increased temperatures, altered precipitation patterns, and the frequency of extreme weather events have been known to affect the growth, yield, and quality of hot pepper crops. For instance, studies have shown that elevated temperatures can lead to a reduction in fruit set and an increase in physiological disorders in peppers, such as Blossom end rot. Moreover, changes in rainfall patterns can exacerbate the incidence of diseases like Phytophthora blight, which thrives in wet conditions, thereby reducing yields. On the other hand, drought conditions can lead to water stress, impacting plant growth and capsaicin concentration, the compound responsible for the pepper's heat. The broader environmental context in which hot pepper cultivation takes place is marked by the pressing issue of greenhouse gas emissions. These emissions, primarily carbon dioxide, are the byproduct of relentless human activities, both industrial and otherwise. They have a profound impact on the planet's climate system, contributing to the greenhouse effect by trapping long-wave radiation from the Earth's surface within the atmosphere. This process leads to a gradual but persistent increase in global temperatures, a phenomenon that has been observed and documented over the centuries. Between the years 1800 and 2012, there was a recorded rise in the Earth's average surface temperature by approximately 0.85°C, a change that underscores the urgency of addressing climate change and its myriad effects. The intersection of agriculture, particularly the cultivation of crops like hot pepper, and environmental sustainability is a complex and multifaceted issue. It requires a delicate balance between meeting the demands of a growing global population for food and spices, and the imperative to mitigate the adverse effects of agricultural practices on the environment. As such, the story of the hot pepper is not just one of culinary delight and agricultural success, but also a narrative deeply intertwined with the challenges and responsibilities of environmental stewardship in the modern world. According to the Intergovernmental Panel on Climate Change's 2021 report, global temperatures are projected to rise by 1.5°C by 2040 and an alarming 2°C by 2050. Heat waves, defined by maximum temperatures exceeding 40°C in plains and 30°C in hilly regions, are set to become more severe. In Pakistan the duration of heat waves could increase twenty-fivefold between 2036 and 2065, as indicated by the G20 Climate Risk Atlas. These escalating temperatures pose a significant threat to agriculture, including the cultivation of hot peppers, which thrives in both tropical and subtropical zones at elevations up to 600 meters. Optimal growth occurs between 20°C and 30°C, as noted by Gopalakrishnan in 2007. However, high temperatures induce stress, impairing hot pepper production. Srivastava and colleagues in 2022 observed that temperatures ranging from 32°C to 38°C lead to increased flower drop, while temperatures above 40°C can result in complete failure of fruit setting. To cope with such changing climate and extreme heat, plants have developed adaptive mechanism (Usman *et al*., 2014; Dahal *et al*., 2006; Srivastava *et al*., 2022). These include variations in leaf size, canopy temperature depression, stomatal density adjustments, ensuring pollen viability, maintaining stigma and ovary health, stabilizing cell membranes, protecting photosystem II, enhancing transpiration rates, and boosting antioxidant enzyme activities. These physiological adaptations are crucial for plant survival under the duress of rising global temperatures. Hot pepper production is facing significant challenges due to climate change. The variability in weather patterns and the increased frequency of extreme events are affecting the yield and quality of hot pepper crops. Addressing these challenges requires a multifaceted approach that includes breeding for resilience, adopting sustainable agricultural practices, and ensuring that policies support the adaptation efforts of farmers and producers worldwide. As the demand for hot peppers continues to grow, so does the need for innovative solutions to sustain its production in the face of climate change. Understanding the genetic basis of pepper heat tolerance is essential for devising strategies to combat heat stress as well as for developing heat tolerant varieties. The objective of the present study was to dissect the genetic architecture underlying climate resilience in hot pepper for which fifteen different hot pepper genotypes evaluated for morphological, physiological characters and yield to exhibit contrasting phenotypic differences for climate resilience.

Material and Methods

At the Vegetable Research Institute in Faisalabad, a nursery of 10 genotypes was established within a tunnel on the 16th of November and the 16th of December, 2022. This method was chosen as chilli plants are susceptible to frost damage. To ensure their survival, the seedlings, measuring 8-10 cm, were transplanted to the field when the threat of frost had passed, specifically on the 17th of February and the 17th of March, 2023. The layout was meticulously planned, with rows spaced 75 cm apart and individual plants 45 cm apart, all set on raised beds covered with mulch or black plastic sheets to conserve moisture and control soil temperature. Drip irrigation was employed to efficiently manage water distribution. The experimental plots were sized at 4.5 meters by 0.75 meters, arranged in a randomized complete block design (RCBD) with three replications. 'Golden Hot F1' and 'HF-86' served as the control checks for the study. Earthing up, a process of drawing soil around the base of the plant, was carried out one month post-transplantation to support the plants and promote root development. The fertilization regime was carefully calculated, with 66.46.25 kilograms of NPK per acre. At the initial stages of field preparation and transplanting, two bags of DAP and one bag of potash were applied. Urea was added in increments, with half a bag used during earthing up and the remainder split into 2-3 applications to ensure optimal nutrient availability. The maximum (day temperature) and minimum (night temperature) temperature during the crop-growing period (February-July) ranged from 24 to 46.5°C and 8 to 30.5°C respectively. Morphological characteristics were meticulously documented. The Plant Height (PH) was recorded in centimeters using a precise scale. Additionally, the count of primary branches (PB) and the number of fruits per plant (NFPP) were carefully enumerated. An electronic weighing balance facilitated the quantification of the Fruit Yield per Plant (FYP),Average fruit weight and the weight of 100 seeds (100SW), all of which were expressed in grams. Leaf length and leaf width were measured with scale in centimeters. Physiological traits were also assessed; Canopy Temperature (CT) was measured in degrees Celsius using a Fluke-62-Max handheld infrared thermometer. Pollen viability (PV) was determined as a percentage (%) using the acetocarmine test (2.5%). The Normalized Difference Vegetation Index (NDVI), a dimensionless indicator reflecting plant cover and vitality, was captured with a Handheld-505 green seeker. Lastly, the Net Photosynthetic Rate (NPR) was measured on fully mature leaves under optimal sunlight conditions between 9.00 and 11.00 AM using a LI-6400 portable photosynthesis system, with the rate expressed in micromoles of carbon dioxide per square meter per second. The relative chlorophyll content (RCC) of the topmost recently matured leaves was measured with CCM-200 plus chlorophyll meter (Opti-Sciences, Inc., Hudson, USA).

Results and Discussion

In this study, several plant genotypes were examine to understand their growth characteristics, yield potential, and leaf attributes. The experiment was conducted at two date of sowing normal 17-02-2023 plant height and 17-03-2023. The data was recorded at anthesis tage and at maturity. The results of normal sowing date presented in table 1. Plant height is a crucial parameter for understanding the growth characteristics of different genotypes VRIHP006 indicated a plant height of 65.1 cm and remained short heighted HF-86 indicated a plant height of 40.2 cm. NPB (Number of Primary Branches) represents the count of primary branches on each plant and reflects branching patterns and overall plant architecture. For instance VRIHP006 has 12.67 primary branches and HF-86 has 7.0 primary branches. Number of Fruits per Plant indicates how many fruits each plant produces and essential for assessing fruit production efficiency VRIHP006 produces 180 fruits per plant and o

HF-86 produces 150 fruits per plant. FYP (g) (Fruit Yield per Plant) represents the total weight of fruits produced by each plant genotype. Genotype VRIHP006 produced highest yields 272.1 grams of fruit per plant and HF-86 yields 230.2 grams of fruit per plant. Average Fruit Weight indicates the average weight of individual fruits produced by each plant. Result showed that VRIHP006 has an average fruit weight of 22.0 grams and HF-86 indicated lowest an average fruit weight of 16.8 grams. The 100 SW specifies the weight of 100 seeds from each genotype and relevant for seed quality assessment. Results manifested that VRIHP006 has a 100-seed weight of 0.40 grams and HF-86 had lowest 100-seed weight of 0.20 grams. Leaf Length represents the length of the leaves in centimeters. Leaf length influences photosynthesis and overall plant health. Results manifested VRIHP006 had leaf length of 8.2 cm an HF-86 indicated a leaf length of 7.10 cm. LW (cm) (Leaf Width) the width of the leaves measured in centimeters. Leaf width is another critical factor for assessing plant health and vigor. Genotype VRIHP006 had a highest leaf width of 3.2 cm and genotype HF-86 had lowest leaf width of 2.1 cm. The results of late sowing 17-03-2023 presented in table 2. Genotype VRIHP006 exhibits the tallest plant height at 35.1 cm, followed by VRIHP004 at 32.3 cm. HF-86 is the shortest genotype, with a height of 18.2 cm. VRIHP006 has the highest number of primary branches (8.67), indicating a well-branched structure. HF-86 also shows significant branching with 3.0 primary branches. VRIHP006 produces the most fruits, with 100 per plant. HF-86 yields 55 fruits per plant, the lowest among the genotypes. VRIHP006 achieves the highest fruit yield, totaling 200.1 g and HF-86 yields 160.2 g of fruit per plant. Genotype VRIHP006 produces fruits with an average weight of 10.0 g. and HF-86 has smaller fruits, with an average weight of 4.8 g. VRIHP006 seeds weigh 0.20 g per 100 seeds while HF-86 seeds are lighter, weighing 0.5 g per 100 seeds. VRIHP006 has longer leaves, measuring 7.2 cm in length. HF-86 exhibits shorter leaves, with a length of 6.10 cm. VRIHP006 leaves are broader, with a width of 2.2 cm and HF-86 leaves are narrower, measuring 1.1 cm in width. Assesment of physiological traits under two different sowing dates present in Fig 1 and Fig 2 respetively. The results of physiological traits correlate with morphological traits and found that VRIHP006 exhibits the highest canopy temperature at 35.1°C, indicating potential heat stress and HF-86 maintains a cooler canopy with a temperature of 18.2°C. Normalized Difference Vegetation Index (NDVI) data analysis indicated that VRIHP006 has the highest NDVI value of 0.84, suggesting robust photosynthetic activity and healthy vegetation while HF-86 shows a lower NDVI of 0.55, possibly indicating stress or suboptimal growth. VRIHP006 boasts substantial pollen viability with 92.8% while HF-86 exhibits lower at 55%. Genotype VRIHP006 had photosynthetic rate of 20.73, signifying efficient resource utilization and growth while HF-86 maintains a similar NPR of 16.2. Relative chlorophyll contents of VRIHP006 had a higher RCC at 14.73, suggesting and HF-86 also maintains a comparable but lowest value of RCC of 13.4. The results of late sowing of physiological traits presented in Fig 2. The results indicated slide change in values and performance of genotypes. Critical Temperature (CT) value represents a critical temperature associated with each genotype. VRIHP006 has the highest CT (37.1) and NDVI (0.61), indicating better health. Golden Hot F1 has the lowest NPR (11.2) and RCC (10.5), suggesting it might be less healthy. HF-86 has a moderate NDVI (0.40) and NPR (10.2). Genotype VRIHP006 and VRIHP004 have the highest Pollen viability (68% and 64%, respectively) and HF-86 has the lowest PV (45%). Golden Hot F1 has the lowest NPR (11.2), indicating potential stress and VRIHP006 has the highest NPR (17.5). Genotype VRIHP006 has the highest RCC (13.8), suggesting a strong relative chlorophyll contents and HF-86 has the lowest RCC (9.4). Climate change have multiple effects and controlled with complex traits and can be estimated indirectly through yield and yield contributing traits under stress, therefore the phenotyping was done for different traits governing morphological, physiological and yield related traits. A wide range of variability was recorded among the genotypes for all the studied traits. High temperature is a critical determinant that profoundly impacts the cultivation of hot pepper in tropical, subtropical and arid regions. It affects both the vegetative and reproductive stages of the crop, leading to flower and fruit abscission, ultimately resulting in a significant reduction in hot pepper yield (Srivastava et al., 2022). The genotypes under scrutiny in this investigation exhibited an extensive spectrum of variations across various traits, aligning harmoniously with previous studies conducted in different crops (Poli *et al*., 2013; Xu *et al*., 2017; Song *et al*., 2020; Jha *et al*., 2021; Liu *et al*., 2021). This observation underscores the inherent quantitative nature of climate resilience, as affirmed by the work of Farnham and Bjorkman (2011). Moreover, multiple prior studies have proposed the polygenic control of climate resilience (Jha *et al*., 2014), further substantiating the complexity of this phenomenon. The plant height had positive correlation with number of fruits per plant, fruit yield per plant and hundred seed weight, indicates that better vegetative growth helps mitigate the negative effects of high temperatures on reproductive parameters. Similar positive correlations between plant height and yield under high temperatures have been reported in previous studies (Khodarahmpour, 2012; Mason and Singh, 2014). Positive correlations of the number of fruits per plant with average fruit weight, fruit and yield per plant are consistent with previous studies demonstrating positive associations between fruit yield and the number of fruits, (Poudyal *et al*., 2018; Rajametov *et al*., 2021). Leaf length and width association with yield supporting the earlier suggestion by Guo *et al*. (2018) regarding the relationship between different leaf parameters perimeter with average fruit length and weight, observed in this study may be attributed to the relative change of photosynthetic area with leaf size (Nicotra *et al*., 2011). The positive associations between the number of fruits per plant and canopy temperature, as well as between both the number of fruits and yield with NDVI, and PV, indicate that physiological processes under high temperatures play a crucial role in the reproductive success of plants. Previous studies have also suggested positive correlations between yield under heat stress and pollen viability Saint Pierre *et al*., 2010; Akhtar *et al*., 2012; Lopes and Reynolds, 2012; Kumari *et al*., 2013; Mondal *et al*., 2013; Pinto *et al*., 2016; Xu *et al*., 2017). Conversely, canopy temperature is negatively correlated with hundred seed weight due to reduced pollination and fertilization and increased malformed seeds (Paliwal *et al*., 2012). Furthermore, it was also found that canopy temperature canopy temperature was negatively associated with leaf length and leaf width. This suggests that due to reduced epidermal cell expansion, smaller leaves are which in turn increases transpiration cooling, making the plant canopy cooler and reducing heat (Beerling and Chaloner, 1993). The negative association between leaf length and leaf width with chlorophyll contents can be attributed to the fact that chlorophyll levels in leaves are directly proportional to their photosynthetic capacity, and narrower leaves have a smaller photosynthetic area (Nicotra *et al*., 2011, Ogweno *et al*., 2008; Asthir, 2015).

Table 1: Morphological and yield traits of genotypes at normal sowing 17-02-2023

Genotypes	PH(cm)	NPB	NFPP	FYP (g)	AFW (g)	100SW (g)	LL (cm)	LW(cm)
VRIHP006	65.1	12.67	180	272.1	22.0	0.40	8.2	3.2
VRIHP004	62.3	10.2	158	260.2	20.2	0.38	7.9	3.1
VRIHP002	50.1	9.67	155	255.2	19.3	0.35	7.78	2.98
VRIHP001	49.2	9.1	152	250.3	18.2	0.33	7.65	2.87
VRIHP003	58.2	8.7	148	247.6	18.1	0.30	7.56	2.78
VRIHP005	45.3	8.1	140	243.2	17.5	0.28	7.40	2.60
VRIHP007	43.2	7.5	138	240.6	17.3	0.25	7.30	2.48
'Golden Hot F1	42.6	7.0	153	235.2	17.0	0.23	7.21	2.35
VRIHP008	41.6	7.0	151	232.2	17.0	0.21	7.15	2.20
HF-86	40.2	7.0	150	230.2	16.8	0.20	7.10	2.1

PH (Plant height), NPB (Number of Primary Branches), NFPP(Number of Fruits per Plant), FYP (Fruit Yield per plant), AFW (Average Fruit Weight), 100 SW (100 seed weight) LL (Leaf length), LW (Leaf width).

Table 2: Morphological and yield traits of genotypes at normal sowing 17-03-2023

Genotypes	PH(cm)	NPB	NFPP	FYP (g)	AFW (g)	100SW (g)	LL (cm)	LW(cm)
VRIHP006	35.1	8.67	100	200.1	10.0	0.20	7.2	2.2
VRIHP004	32.3	7.2	88	195.2	8.2	0.15	6.9	2.1
VRIHP002	30.1	6.67	75	190.2	7.3	0.10	6.78	1.98
VRIHP001	29.2	5.1	72	185.3	6.2	0.9	6.65	1.87
VRIHP003	28.2	4.7	68	180.6	6.1	0.7	6.56	1.78
VRIHP005	25.3	4.1	64	175.2	6.0	0.6	6.40	1.60
VRIHP007	23.2	3.5	60	170.6	5.8	0.5	6.30	1.48
'Golden Hot F1	19.6	3.0	59	165.2	5.0	0.5	6.21	1.35
VRIHP008	19.3	3.0	58	162.2	5.0	0.5	6.11	1.25
HF-86	18.2	3.0	55	160.2	4.8	0.5	6.10	1.1

PH (Plant height), NPB (Number of Primary Branches), NFPP(Number of Fruits per Plant), FYP (Fruit Yield per plant), AFW (Average Fruit Weight), 100 SW (100 seed weight) LL (Leaf length), LW (Leaf width).

Figure 1: Physiological traits of genotypes at normal sowing 17-02-2023

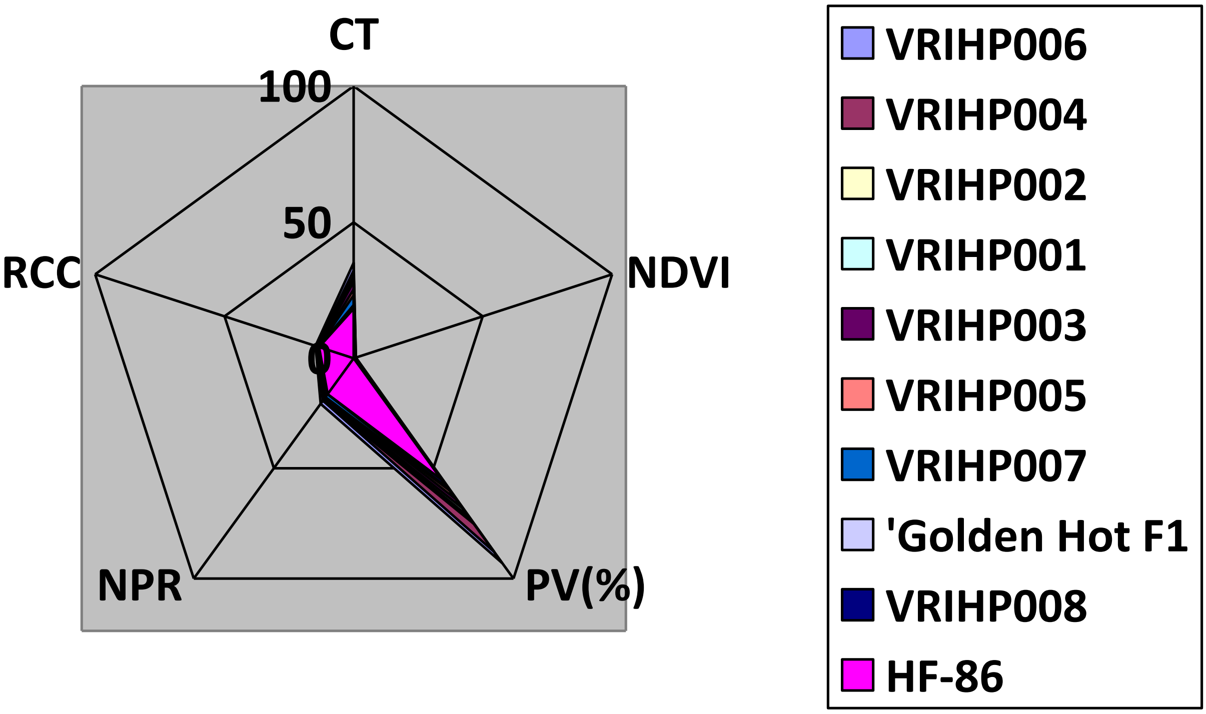
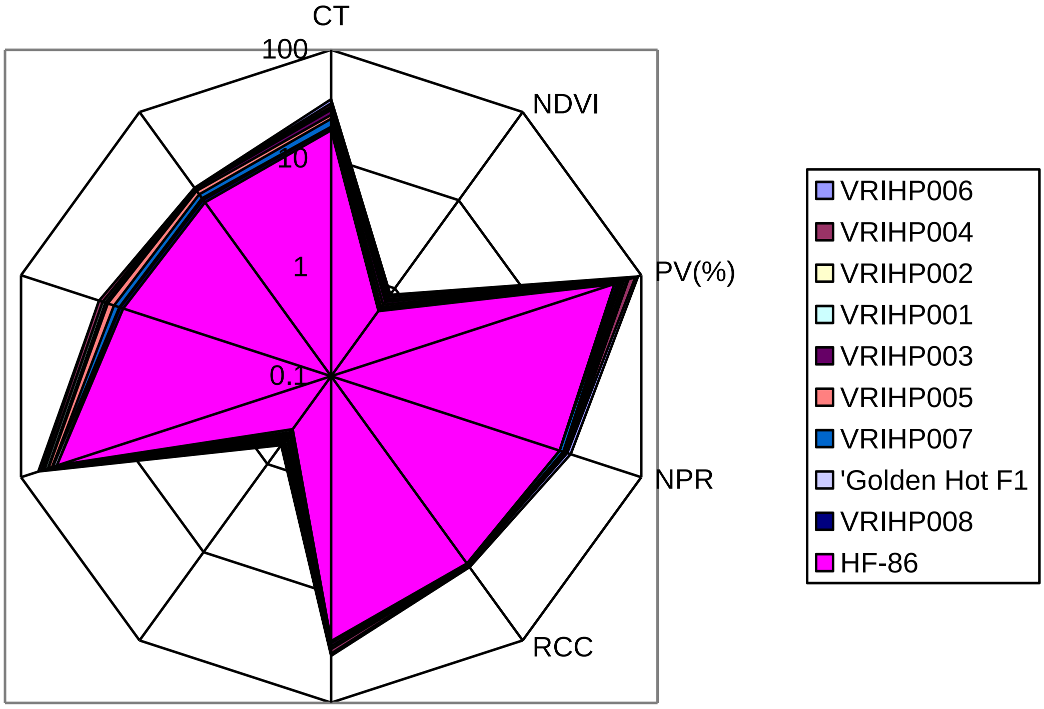


Figure 2: Physiological traits of genotypes at late sowing 17-03-2023



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