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Evaluation of Heat Tolerant Genotypes in Sesame (*Sesamum indicum* L.) based on Heat Susceptible Index

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ABSTRACT: Sesame (*Sesamum indicum* L.) is highly susceptible to heat stress, which adversely affects its growth, yield, and overall productivity. This study aimed to evaluate the heat tolerance of different sesame genotypes using the Heat Susceptibility Index (HSI) and key physiological and agronomic traits. The experiment was conducted at SKN College of Agriculture, Jobner during kharif 2023 using a randomized complete block design (RCBD) with three replications under both normal and heat stress conditions. A total of thirty-six (eight parents and twenty-eight F1's) sesame genotypes were assessed for yield performance, chlorophyll content, relative water content, membrane stability index, and proline accumulation, which are critical indicators of heat stress adaptation. Results showed a significant reduction in yield and other agronomic traits under heat stress, highlighting the adverse impact of high temperatures. However, genotypes RT-386, MT-5-04, VS-16-009, EC-370934, and IC-43135 exhibited superior heat tolerance, making them promising candidates for breeding programs. Early flowering and maturity were found to be beneficial in mitigating heat stress effects. Furthermore, hybrid combinations such as EC-370934 × IC-43135 and MT-5-04 × IC-43135 demonstrated stability under high-temperature conditions, suggesting their potential for heat-resilient sesame breeding. The findings provide valuable insights into the genetic basis of heat tolerance in sesame and emphasize the need for developing climate-resilient varieties.

Keywords: Heat stress, Heat Susceptibility, Tolerance, Temperatures, Genotypes, maturity, Stability, Abiotic stresses.

INTRODUCTION

Sesame (*Sesamum indicum* L.) is one of the oldest and most important oilseed crops, widely cultivated in tropical and subtropical regions for its high-quality edible oil, which contains essential fatty acids, antioxidants, and lignans such as sesamin and sesamol (Bedigian, 2010; Anilakumar *et al*., 2010). It is valued for its high oil content (40–60%) and nutritional benefits, making it a key component in human diets and industrial applications (Weiss, 2000). Sesame is predominantly grown in India, China, Sudan, and Nigeria, contributing significantly to global oilseed production (FAO, 2021).

Despite its economic and nutritional importance, sesame is highly susceptible to abiotic stresses, particularly heat stress, which significantly affects its growth, development, and yield (Dossa *et al*., 2017). High temperatures during the reproductive and grain-filling stages cause pollen sterility, reduced seed setting, and lower oil content, leading to yield losses (Wahid *et al*., 2007). Sesame has been reported to exhibit varying degrees of heat tolerance across genotypes, which makes the identification of heat-tolerant varieties crucial for breeding programs aimed at improving crop resilience (Kumar *et al*., 2020).

Plants respond to heat stress through various physiological and biochemical mechanisms, including increased production of heat shock proteins, maintenance of membrane stability, accumulation of osmolytes like proline, and enhanced antioxidant enzyme activity (Hasanuzzaman *et al*., 2013). The ability of genotypes to tolerate high temperatures can be assessed using stress indices such as the Heat Susceptibility Index (HSI), which quantifies yield reduction under heat-stress conditions relative to a non-stress environment (Fischer and Maurer 1978).

Several studies have employed HSI to identify heat-tolerant genotypes in oilseed crops such as sunflower (Kumar *et al*., 2015) and mustard (Kaur *et al*., 2019). However, limited research has systematically evaluated heat tolerance in sesame using HSI, despite the crop's significance in semi-arid and arid regions (Dossa *et al*., 2019). Screening sesame genotypes based on HSI could aid in selecting superior heat-tolerant lines for breeding programs focused on developing climate-resilient varieties (Reddy *et al*., 2017).

The present study aims to evaluate the heat tolerance of sesame genotypes based on their Heat Susceptibility Index under different environmental conditions. The findings will provide valuable insights into the selection of heat-tolerant genotypes and contribute to the development of climate-smart sesame varieties for sustainable oilseed production

MATERIAL AND METHODS

A. Experimental Material

The present study was conducted using eight diverse sesame (*Sesamum indicum* L.) genotypes, selected for their adaptability and geographical origin. The experimental material was sourced from the Department of Plant Breeding and Genetics, SKN College of Agriculture, Jobner and the Agricultural Research Station, Mandor, Jodhpur. The selected parental genotypes included **RT-351, RT-386, AT-413, DS-61, MT-5-04, VS-16-009, EC-370934, and IC-43135**. These genotypes were crossed in a **half-diallel mating design** (excluding reciprocals) using standard **hand emasculation and controlled pollination techniques** to develop F_1 hybrids.

B. Experimental Design and Field Evaluation

The field experiment was conducted under **early sown (E_1) and normal sown (E_2) conditions** to assess heat tolerance. The experimental layout followed a **randomized complete block design (RCBD)** with three replications. Each genotype and hybrid were sown in rows of uniform length, maintaining recommended agronomic practices throughout the cropping season.

Estimation of Heat Susceptibility Index (HSI)

The **heat susceptibility index (HSI)** was calculated for seed yield and other agronomic traits following the formula proposed by **Fischer and Maurer (1978)**:

HSI = [1- YD/YP]/ D

Where, YD = mean of the genotype in stress environment

YP = mean of the genotype in non- stress environment

D = 1- [mean YD of all genotype/ mean YP of all genotypes].

The HSI values were used to characterize the relative tolerance of genotypes based on minimization of yield losses compared to normal environmental conditions.

C. Statistical Analysis

All recorded data were subjected to **analysis of variance (ANOVA)** to determine the significance of genotype and treatment interactions. Statistical analysis was performed using **R software.**

RESULTS AND DISCUSSION

Heat stress is a significant abiotic factor that negatively impacts the yield of sesame (*Sesamum indicum* L.), similar to other crops like wheat. Identifying heat stress-tolerant sesame genotypes is crucial for maintaining productivity, especially given the increasing occurrence of extreme temperatures due to climate change. Heat stress during critical stages, such as flowering and seed filling, can severely impact physiological and biochemical processes, including photosynthesis, membrane stability, and enzyme activity, ultimately leading to reduced oil content, seed weight, and overall seed quality (Weiss, 2000; Belayneh *et al*., 2021). Studies have shown that high temperatures can impair pollen viability and fertilization, significantly lowering seed set in sesame (Dossa *et al*., 2019).

The challenges posed by heat stress are particularly evident in countries like India, where rising temperatures are increasingly affecting sesame productivity (Reddy *et al*., 2017). Therefore, breeding efforts focused on selecting sesame varieties with heat stress tolerance are essential to ensure stable yields and maintain oil quality under varying temperature conditions.

The Heat Susceptibility Index (HSI) is a valuable parameter for assessing the reduction in performance of test genotypes under heat stress conditions and is widely used to identify heat-tolerant genotypes in crop breeding programs (Fischer and Maurer 1978). The present study demonstrated a significant reduction in the mean performance of parents and F1 hybrids under the heat stress environment (E1) compared to the normal sown environment (E2) for all traits, except proline content. This aligns with previous studies indicating that heat stress leads to impaired growth and reduced seed yield in sesame (Reddy *et al*., 2017; Dossa *et al*., 2019).

The HSI was calculated for each character, and genotypes were classified into four categories: highly heat-tolerant (HSI < 0.50), heat-tolerant (HSI: 0.51-0.75), moderately heat-tolerant (HSI: 0.76-1.00), and heat-susceptible (HSI > 1.00). Genotypes with high positive HSI values exhibited greater susceptibility to heat stress, whereas those with low HSI values were identified as heat-tolerant.

An evaluation of the results (Table 1) indicated that several parental genotypes exhibited superior tolerance to heat stress. Specifically, RT-386, EC-370934, RT-351, IC-43135, and MT-5-04 were least affected for **days to 50% flowering,** whereas VS-16-009, IC-43135, RT-351, and AT-413 showed tolerance for **days to maturity**. Traits such as **plant height, primary branches per plant, capsules per plant, capsule length, seeds per capsule, 1000-seed weight, and seed yield per plant** were least affected in heat-tolerant genotypes such as RT-386, AT-413, VS-16-009, and EC-370934.

Additionally, RT-386, IC-43135, and VS-16-009 exhibited stability in **oil content** under heat stress conditions. Physiological traits like **chlorophyll content (SPAD), relative water content (RWC), membrane stability index (MSI), and proline content** were significantly higher in heat-tolerant genotypes, particularly MT-5-04, EC-370934, DS-61, and RT-386. These findings are in agreement with earlier reports suggesting that high chlorophyll retention, stable relative water content, and increased proline accumulation are crucial indicators of heat tolerance in sesame (Belayneh *et al*., 2021; Kumar *et al*., 2022).

A comprehensive assessment of parental lines based on HSI revealed that **RT-386, MT-5-04, VS-16-009, EC-370934, and IC-43135** were the most desirable genotypes for **seed yield per plant** and associated yield-contributing traits under heat stress conditions. These genotypes demonstrated resilience to high temperatures, suggesting their potential for use in breeding programs aimed at improving heat tolerance in sesame. Previous studies have also identified RT-386 and EC-370934 as promising heat-tolerant sesame genotypes with stable performance under high-temperature conditions (Dossa *et al*., 2019; Reddy *et al*., 2017).

Early flowering and maturity are important traits for heat tolerance, as they allow crops to escape the terminal heat stress (Wahid *et al*., 2007). The crosses **EC-370934 × IC-43135, MT-5-04 × IC-43135, and RT-351 × RT-386** exhibited the lowest HSI values for **days to 50% flowering,** suggesting that these combinations are well-suited for early flowering under heat stress. Similarly, **RT-351 × EC-370934, RT-386 × MT-5-04, and MT-5-04 × IC-43135** were superior for **days to maturity**, indicating their ability to complete the life cycle faster, thereby avoiding exposure to prolonged heat stress (Hasanuzzaman *et al*., 2013).

Plant height is a crucial trait that determines biomass accumulation and stress adaptability (Ashraf & Harris 2013). In this study, **RT-351 × MT-5-04, RT-386 × VS-16-009, and AT-413 × DS-61** recorded higher plant heights, suggesting their ability to sustain growth under elevated temperatures. Similarly, **EC-370934 × IC-43135, RT-386 × IC-43135, and DS-61 × IC-43135** exhibited increased **primary branches per plant**, indicating their potential for maintaining vegetative vigor despite heat stress (Mittler, 2006).

Yield components such as **capsules per plant, capsule length, seeds per capsule**, and **1000-seed weight** were significantly influenced by heat stress (Hall, 2001). The maximum **capsules per plant** were recorded in **DS-61 × IC-43135, DS-61 × EC-370934, and AT-413 × MT-5-04,** while **capsule length** was highest in **RT-386 × IC-43135, RT-386 × AT-413, and RT-351 × AT-413.** Higher **seeds per capsule** were noted in **EC-370934 × IC-43135, DS-61 × IC-43135, and RT-351 × EC-370934,** and the best-performing crosses for **1000-seed weight** were **DS-61 × IC-43135, DS-61 × VS-16-009, and EC-370934 × IC-43135.**

Seed yield per plant, the most critical economic trait, was found to be highest in **RT-386 × DS-61, EC-370934 × IC-43135, and DS-61 × EC-370934.** The stability of yield in these hybrids suggests the presence of favorable genetic interactions contributing to stress resilience. Additionally, **oil content**, an important trait in oilseed crops, was maximized in **DS-61 × IC-43135, VS-16-009 × EC-370934, and RT-351 × VS-16-009**, indicating their suitability for high-temperature environments.

Heat stress affects photosynthetic efficiency, water retention, and cellular stability, which are key determinants of crop resilience. The **chlorophyll content (SPAD values)** was highest in **RT-351 × RT-386, DS-61 × VS-16-009, and AT-413 × DS-61**, reflecting their efficiency in maintaining photosynthesis under heat stress. The highest **relative water content (RWC)** was observed in **MT-5-04 × EC-370934, RT-386 × IC-43135, and DS-61 × IC-43135,** indicating superior water retention capability (Siddique *et al*., 2000). **Membrane stability index (MSI),** a crucial indicator of heat tolerance, was highest in **AT-413 × DS-61, AT-413 × VS-16-009, and AT-413 × EC-370934,** signifying their ability to maintain cellular integrity under heat stress (Blum, 2011).

Furthermore, **proline content**, an Osmo protectant known to mitigate oxidative stress, was maximized in **RT-351 × VS-16-009, RT-351 × MT-5-04, and EC-370934 × IC-43135**. The accumulation of proline enhances cellular homeostasis and protects plants from heat-induced oxidative damage (Ashraf and Foolad 2007).

Based on overall HSI values, the crosses **RT-386 × DS-61, EC-370934 × IC-43135, DS-61 × EC-370934, AT-413 × VS-16-009, RT-351 × VS-16-009, RT-386 × EC-370934, RT-386 × VS-16-009, RT-351 × RT-386, RT-351 × MT-5-04, DS-61 × IC-43135, VS-16-009 × IC-43135, RT-351 × DS-61, DS-61 × VS-16-009, and VS-16-009 × EC-370934** showed superior performance under early sown conditions (E_1) for seed yield per plant and other traits. These crosses possess desirable genetic combinations that confer heat tolerance, making them promising candidates for breeding programs aimed at developing climate-resilient cultivars.

The magnitudes of heat stress intensity (D-value) are presented in Table 1. A low D-value (<0.20) indicated higher tolerance in traits such as days to 50% flowering (0.08), days to maturity (0.07), plant height (0.18), primary branches per plant (0.20), capsules per plant (0.16), capsule length (0.11), seeds per capsule (0.18), 1000-seed weight (0.06), oil content (0.05), chlorophyll (SPAD) (0.06), relative water content (0.07), membrane stability index (0.07), and proline content (-0.66). Conversely, seed yield per plant exhibited high heat stress intensity (D-value 0.26), indicating its sensitivity under early sown heat stress conditions (E1) (Kaur and Behl 2010; Kumar *et al*., 2018).

The results of the present study confirm that compared to normal sown conditions (E2), the mean performance of parents and F1 hybrids declined under early sown heat stress (E1) for all traits except proline content. Yield is a complex trait influenced by multiple component traits; thus, selection solely based on yield may not be effective (Manohar *et al*., 2014; Bhardwaj *et al*., 2017). To assess the tolerance of different parents and crosses to heat stress, the heat susceptibility index (HSI) and heat tolerance indices were estimated based on the desirability of different traits. Genotypes with high HSI values were more susceptible to elevated temperatures, whereas those with low HSI values were more tolerant (Hossain *et al*., 2013; Limenie *et al*., 2021).

Among the parental genotypes, RT-386, MT-5-04, VS-16-009, EC-370934, and IC-43135 exhibited the least reduction in performance under heat stress. Among the crosses, RT-386 × DS-61, EC-370934 × IC-43135, DS-61 × EC-370934, AT-413 × VS-16-009, RT-351 × VS-16-009, and RT-386 × EC-370934 had HSI values below 0.50, suggesting their superior performance under early sown conditions (E1) (Ramani *et al*., 2014; Kumar *et al*., 2018). The greater heat tolerance value indicates larger yield reductions under heat stress conditions, highlighting the heat sensitivity of certain crosses (Choudhary, 2022).

Traits with low D-values (<0.20), such as days to 50% flowering, days to maturity, oil content, relative water content, membrane stability index, and proline content, were more tolerant under early and late sown conditions. These findings align with previous studies (Hossain *et al*., 2013; Ramani *et al*., 2014; Kumar *et al*., 2018; Choudhary, 2022). This suggests that these traits could serve as key selection criteria in breeding programs aimed at developing heat-tolerant genotypes.

Table 1: Heat susceptibility index (HSI) for yield and its contributing attributes in E_1 in comparison to E_2 environment.

Parents	Days to 50% flowering	Days to maturity	Plant height (cm^2)	Primary branches per plant	Capsules per plant	Capsule length (cm)	Seeds per capsule	1000-seed weight (g)	Seed yield par plant (g)	Oil content (%)	Chlorophyll (SPAD)	RWC (%)	MSI (%)	Proline (µg/g)
RT-351	0.75	0.85	0.96	0.97	1.03	1.25	0.89	1.06	1.11	1.28	1.49	0.65	1.57	1.27
RT-386	0.56	1.01	0.93	0.97	1.06	1.13	0.79	0.98	0.81	0.10	0.48	0.81	0.45	0.99
AT-413	1.94	0.86	0.95	0.76	1.26	1.38	0.83	1.58	1.33	1.13	1.34	0.99	0.69	1.06
DS-61	1.29	1.44	1.13	0.96	0.95	1.11	1.04	1.15	1.11	1.06	0.03	1.56	0.91	0.83
MT-5-04	0.82	1.30	1.12	1.33	0.80	1.09	1.13	1.02	0.83	1.11	0.20	0.91	1.37	0.74
VS-16-009	1.16	0.71	0.70	1.08	0.90	0.94	0.93	0.57	0.94	0.96	0.22	1.14	0.75	1.19
EC-370934	0.65	1.02	1.11	1.06	0.90	0.31	1.35	0.45	0.89	1.56	2.83	0.36	1.18	0.82
IC-43135	0.76	0.78	1.11	0.85	1.10	0.71	1.03	1.20	0.98	0.83	1.40	1.50	1.07	1.18
Crosses														
RT-351 × RT-386	0.18	0.61	1.80	1.18	1.24	1.05	1.18	1.00	0.91	1.11	0.07	1.74	0.79	1.33
RT-351 × AT-413	1.13	1.85	1.28	0.83	1.44	0.57	0.68	0.78	1.05	1.44	0.91	0.42	1.18	0.73
RT-351 × DS-61	1.20	0.91	0.81	0.98	1.01	0.98	0.99	1.16	0.96	0.66	1.86	0.77	1.10	0.97
RT-351 × MT-5-04	0.72	1.25	0.08	0.74	0.96	0.75	1.19	2.91	0.95	0.93	1.07	0.61	1.71	0.47
RT-351 × VS-16-009	1.31	0.66	1.10	1.52	0.75	1.10	1.13	1.10	0.84	0.12	0.71	1.52	1.41	0.29
RT-351 × EC-370934	1.59	0.50	1.33	1.18	1.16	1.05	0.56	1.03	1.14	0.98	0.94	0.61	0.87	2.24
RT-351 × IC-43135	1.65	1.03	0.89	0.59	0.93	1.48	1.07	0.52	1.17	0.25	2.01	1.35	1.28	0.98
RT-386 × AT-413	1.11	1.05	1.17	1.83	0.99	0.15	1.20	1.22	1.69	1.24	0.42	1.31	0.29	0.88
RT-386 × DS-61	1.53	1.10	1.48	0.89	1.28	0.60	1.31	0.99	0.45	0.49	2.17	1.05	0.37	0.74
RT-386 × MT-5-04	1.60	0.50	1.35	1.59	1.32	1.01	0.94	1.17	0.99	1.18	0.68	1.71	1.10	1.07
RT-386 × VS-16-009	0.46	0.97	0.41	1.19	0.69	1.00	0.74	0.27	0.87	0.83	2.50	0.33	0.65	0.96
RT-386 × EC-370934	0.64	0.97	1.16	0.60	0.78	1.18	0.64	0.72	0.86	1.47	0.77	0.92	0.81	0.61
RT-386 × IC-43135	0.72	0.91	0.97	0.16	1.05	0.05	0.68	0.55	1.01	2.22	0.36	0.09	2.49	1.26
AT-413 × DS-61	0.90	0.89	0.51	0.77	1.04	1.18	1.03	0.29	1.17	2.09	0.20	1.07	-0.10	1.11
AT-413 × MT-5-04	1.12	1.18	0.68	1.48	0.52	1.06	1.26	2.27	1.47	1.52	1.70	0.64	1.66	1.11
AT-413 × VS-16-009	0.64	1.12	0.86	1.11	1.06	0.95	1.77	1.22	0.83	0.32	0.76	2.38	0.11	1.69
AT-413 × EC-370934	1.43	1.33	0.69	0.89	1.29	1.06	1.06	0.43	1.12	0.84	1.88	0.97	0.19	1.49
AT-413 × IC-43135	1.93	1.06	1.63	1.25	1.34	1.35	1.34	2.08	1.12	1.57	1.10	1.99	0.53	0.89
DS-61 × MT-5-04	0.37	1.08	0.97	0.92	0.91	0.95	1.19	1.85	1.12	2.75	0.49	0.95	0.75	1.87
DS-61 × VS-16-009	1.49	0.94	0.82	0.88	1.03	1.07	0.93	0.24	0.97	0.59	0.08	0.97	0.76	1.45
DS-61 × EC-370934	1.01	1.54	0.81	0.67	0.49	0.62	0.88	0.79	0.63	0.23	0.33	0.14	1.39	1.02
DS-61 × IC-43135	0.70	0.87	0.91	0.58	0.19	1.47	0.50	0.02	0.95	0.02	0.72	0.91	0.40	0.89
MT-5-04 × VS-16-009	0.55	1.03	0.92	1.26	0.61	1.37	1.30	1.36	1.04	1.84	0.36	0.70	0.80	0.85
MT-5-04 × EC-370934	1.14	1.01	1.38	1.13	1.17	1.02	0.88	0.81	1.02	0.70	0.85	0.03	1.26	0.82
MT-5-04 × IC-43135	0.09	0.60	1.17	1.36	1.50	1.25	1.05	1.22	0.99	1.31	0.36	1.52	1.18	1.17
VS-16-009 × EC-370934	0.63	0.93	0.89	0.94	1.22	0.94	1.13	1.05	0.97	0.20	0.71	0.29	0.75	0.95
VS-16-009 × IC-43135	1.97	0.61	0.94	1.05	1.00	1.07	1.07	0.38	0.95	0.50	1.25	1.67	1.41	0.93
EC-370934 × IC-43135	-0.19	1.43	0.77	0.12	0.74	1.34	0.24	0.25	0.56	0.37	2.28	0.91	2.49	0.51
D- value	0.08	0.07	0.18	0.20	0.16	0.11	0.18	0.06	0.26	0.05	0.06	0.07	0.07	-0.66

CONCLUSIONS

This study highlights the impact of heat stress on sesame and identifies heat-tolerant genotypes using the Heat Susceptibility Index (HSI). Heat stress significantly reduced yield and agronomic traits, emphasizing the need for resilient varieties. Genotypes RT-386, MT-5-04, VS-16-009, EC-370934, and IC-43135 showed superior heat tolerance, making them promising for breeding programs. Key physiological traits, including chlorophyll content, relative water content, membrane stability index, and proline accumulation, played a role in heat adaptation. Early flowering and maturity also helped mitigate heat stress. Promising hybrids like EC-370934 × IC-43135 and MT-5-04 × IC-43135 showed stability under high temperatures. These findings provide insights into the genetic basis of heat tolerance in sesame.

FUTURE SCOPE

Developing heat-resilient sesame varieties is crucial for ensuring stable yields in high-temperature environments. Advances in genetic and molecular studies, such as QTL mapping, GWAS, and gene editing, can help identify key genes responsible for heat tolerance. Understanding physiological and biochemical mechanisms, including heat shock proteins, antioxidant enzymes, and Osmo protectants, provides insights into stress adaptation. Effective agronomic practices for heat stress management, such as optimized irrigation, nutrient application, and biostimulants, can enhance crop resilience. Implementing climate change adaptation strategies, such as integrating heat-tolerant genotypes into climate-smart farming, is essential for future agricultural sustainability. Additionally, expanding sesame cultivation in heat-prone areas with improved varieties can help maintain productivity and support global food security amidst rising temperatures.

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