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RESEARCH ARTICLE

Chilling stress effects on growth and development of Panivaragu (*Panicum milliaceum* L.) genotypes

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Abstract

Temperature stress was the most critical environmental factor that restricted plant growth, impaired physiological and biochemical processes and ultimately reduced productivity worldwide. Cold temperatures, especially low temperatures, significantly reduced seedling growth and extended the flower initiation period (50 - 55 Days After Sowing (DAS)) during the crop growth and development period of Panivaragu (*Panicum milliaceum* L.). Small millets were drought tolerant in general. Even though it was a drought-tolerant crop, it did not tolerate cold temperatures. When compared with conventional cultivation, total dry matter production was very low at cold temperature. As a result, yield loss was severe. When compared to coarse cereals like wheat and rice, small millets were extremely high in protein, fibre and minerals. The field experiment was conducted with Panivaragu (TNPm 238, TNPm 247, TNPm 255, TNPm 274, TNPm 280 and TNPm 282) at Agricultural College and Research Institute, Vazhavachanur, during *Rabi* season. The Panivaragu genotype TNPm 280 followed by TNPm 282 performed well under low temperature condition with a smaller reduction in plant height (from 44.6 to 41.8 cm). The Panivaragu genotypes TNPm 280 and TNPm 282 recorded greater 1000 grain weight (4.60 g), highest grain yield (1873 kg/ha) and straw yield (1990 kg/ha) compared to other genotypes.

Keywords: crop growth rate; grain yield; leaf area; Panivaragu; straw yield

Introduction

The productivity of small millet was very low in Tiruvannamalai District during *Rabi* season. In this zone, the temperature dropped very low (below 21 °C) during the month of December and January, resulting in poor growth of small millet seedlings. Low temperatures greatly hindered seedling growth and delayed flower initiation to 50-55 DAS during the crop's growth and development stage. Temperature stress was the most vital environmental constraint that hindered plant growth, disrupted physiological and biochemical functions and ultimately reduced productivity worldwide. All plant species required the optimal temperature to develop and complete their life cycle. Apart from other environmental stresses, low temperature was an important environmental factor that limited plant survival, metabolism and productivity.

Low temperature affected all the physiological processes like photosynthesis, chlorophyll content, respiration, crop growth rate and total dry matter production of plants (1). A chilling injury was one that resulted from a temperature drop above the freezing point but below 15 °C. The rapid drooping of the leaves and the development of water-soaked patches were signs of chilling damage. Small millets became a very well-liked food worldwide. Many small millets were grown by the hill people. Despite being a crop that withstood drought, it could not tolerate cold temperatures (2). Small millets were incredibly high in protein, fibre and minerals when compared to coarse grains like rice and wheat. As a result, millets were now referred to as "nutria-cereals and miracle grains". Comparing millets to other crops, they offered numerous nutritional and health advantages (3). At low temperatures, Panivaragu, in particular, prolonged the flower initiation days and reduced vegetative growth and development. The overall amount of dry matter produced at extremely cold temperatures was quite low when compared to conventional farming (4). Low temperatures caused wilting, necrosis and decreased height in plants. They also altered the lipid content of the cell wall, impacted membrane integrity and resulted in cellular leakage (5, 6). Furthermore, they impacted the protein content and enzymatic activities of the plant (7, 8). Low temperatures also affected cell components like chloroplasts, thylakoid membranes and mitochondria (9, 10). Climate change, water scarcity, population growth, growing food prices and other socioeconomic effects were predicted to pose a serious danger to global agriculture and food security, particularly for the world's poorest citizens.

Plants that were sensitive to cold reduced their growth at several physiological stages; this effect was more noticeable in susceptible species and varieties than in tolerant genotypes (11). Thus, it was imperative that scientists and researchers concentrated more on the long-term production of foxtail millet in low-temperature conditions. Cold tolerance screening in small millets' germplasm was a new cold stress study that paved the way for genetic modification to increase cold tolerance. Low temperature was one of the most significant environmental stressors that restricted plant yield and distribution.

Materials and Methods

A field trial was carried out on Panivaragu, involving 7 genotypes across two locations: Agricultural College and Research Institute in Vazhavachanur, Tiruvannamalai district and Jawadhu hills in Tiruvannamalai district. The base temperature for panivaragu was 9.3 °C, the optimum temperature was 37 °C and the ceiling temperature was 46 °C. The study was designed using a Factorial Randomized Block Design (FRBD) with three replications. In the *Rabi* seasons of 2020 and 2021, the day and night temperatures in the Tiruvannamalai district varied between 12 °C and 24 °C. Moreover, Jawadhu Hill experienced day time and night time temperature ranging from of 9 °C to 20 °C. Most tropical and subtropical plants were affected by low temperatures between 10 °C and 25 °C. These low temperatures caused changes in plant morphological characteristics, such as reduced plant height and leaf area, decreased crop growth rate, delayed flower initiation and eventually yield reduction.

Treatment Details

Factor - Two

Factor A - Genotypes

Levels - Seven

Factor B - Locations

Levels - Two (Agricultural College and Research Institute, Vazhavachanur, Tiruvannamali district and Jawadhu hills)

Varietal Details

Six advanced cultures of Panivaragu, along with one check variety were evaluated in the study. The advanced cultures included TNPm 238, TNPm 247, TNPm 255, TNPm 274, TNPm 280 and TNPm 282, while Panivaragu ATL 1 served as the check variety. All genotypes were obtained from the Centre of Excellence in Millets (CEM), Athiyandal, Tiruvannamalai.

All agronomic practices were considered normal for all treatments except those under study. Each entry was sown in three rows with a spacing of 22.5 x 10 cm and the recommended doses of fertilizers and plant protection measures were applied as required.

Measurement Parameters

Leaf Area (LA)

Leaf Area was measured using Leaf Area Meter (Li-Cor Model 3100). The measurement was taken from entire sampling unit and expressed as cm^2 $plant^{-1}$.

Specific Leaf Weight (SLW)

Specific Leaf Weight (SLW), was calculated using the following formula and represented as mg cm^{-2} (12).

$$\text{SLW} = \frac{\text{Leaf dry weight per plant (mg)}}{\text{Leaf area per plant (cm}^2\text{)}}$$

Thousand seed weight

The weight of one thousand randomly selected seeds from each replication and treatment was recorded and expressed in grams (g).

Days to 50 % flowering

The number of days from sowing to the initiation of flowering in 50 % of plant population within each treatment and replication was recorded. The mean values were expressed as days to 50 % flowering.

Grain yield per Plot and per Hectare

Grain yield per hectare was estimated based on mean yield per plot. It was calculated according to plant population and expressed in kilograms per hectare (kg ha^{-1}).

Harvest Index (HI)

The Harvest Index (HI) was determined from the ratio of grain dry weight to total plant dry weight at harvest using the formula.

$$\text{HI (\%)} = \frac{\text{Grain dry weight}}{\text{Whole plant dry weight}} \times 100$$

Statistical analysis

Statistical analysis was performed using earlier described method (13). Difference among treatments were considered statistically significant at $p < 0.05$.

Results and Discussion

Effect of low temperature on morphological characters

Panivaragu was an important food crop in hilly regions. It was capable of growing during the *Rabi* season, as it could be established and harvested despite the cold. However, low temperatures negatively affected panivaragu's growth and establishment. Among various environmental stresses, low temperature was a significant yield-reducing factor causing different physio-chemical changes inside the plant. When the temperature dropped below 15 °C, it impacted both plant establishment and pollination. Plant height was an important morphological character for assessing plant vigor under different growth stages. In the plains of Tiruvannamalai and the hilly regions of Jawadhu Hill. The plant height varied significantly from the vegetative to maturity phase (14, 15). Among the panivaragu genotype TNPm 280 followed by TNPm 282 performed well under low temperature condition with less reduction in leaf area -206.4 cm^2 and 191.9 cm^2 respectively at CEM, Athiyandal. However, leaf area values were much lower in Jawadhu hill (85.7 cm^2 and 84.6 cm^2). The genotype TNPm 280 also maintained a higher specific leaf weight (13.65 mg cm^{-2}) and crop growth rate (12.60 g m^{-2} day^{-1}) during the maturity stage under low temperature stress condition at CEM, Athiyandal (Table 1). Low temperature resulted in the cessation

Table. 1 Effect of low temperature on morphological and yield components of Panivaragu at CEM, Athiyandal

Genotypes	Leaf Area (cm^2 plant^{-1})	Specific leaf weight (mg cm^{-2})	1000 grain weight (gm)	Days to 50 % flowering	Grain yield (kg/ha)	Harvest Index
TNPm 238	172.4	12.48	4.64	43	1233	42.20
TNPm 247	141.3	6.34	4.58	51	1169	40.03
TNPm 255	129.5	7.86	4.38	53	1102	37.23
TNPm 274	124.9	8.45	4.49	55	1269	41.35
TNPm 280	206.4	13.65	5.14	43	1724	43.80
TNPm 282	191.1	7.20	4.61	36	1497	43.43
ATL 1	136.7	6.99	4.40	40	1485	42.64
SEd	4.14	1.46	0.07	0.31	30.87	0.46
CD (P = 0.05)	12.77	4.51	0.22	0.95	95.11	1.42

of growth in panivaragu, leading to reduced energy absorption and subsequently, lower photosynthesis rate (16, 17). Temperature below 15 °C, led to membrane damage, which reduced both leaf area and specific leaf weight due to low diminished production capacity (Table 2).

Effect of low temperature on soluble protein and proline content

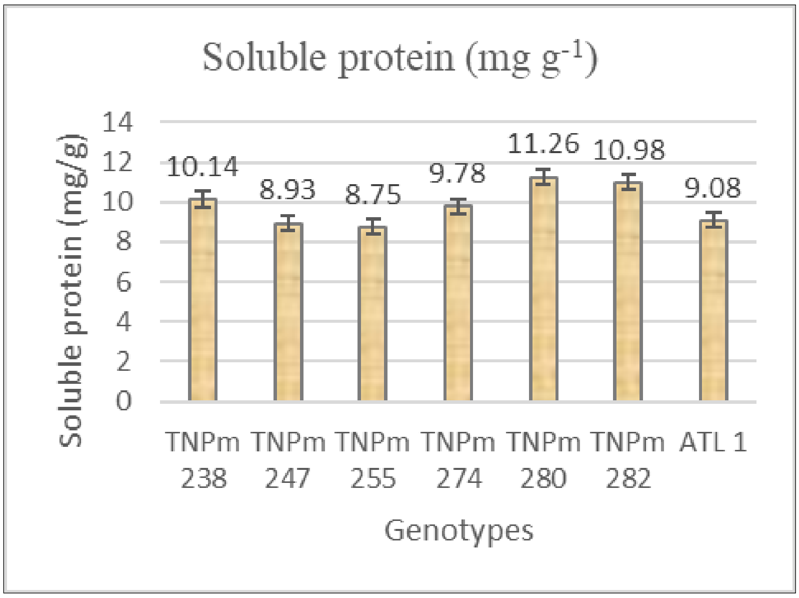
In general, low temperature caused a steep decline in soluble protein content irrespective of stages and genotypes. Soluble protein of the plants influenced photosynthetic rate and thereby enhanced the plant efficiency in biomass production. Among the genotypes, TNPm 280, identified a cold tolerant genotype exhibited, higher soluble protein content of 12.20 mg g^{-1} and 12.30 mg g^{-1} at Jawadhu hill region (Fig 1). The highest proline content was also recorded in TNPm 280- 906 µg g^{-1}at CEM, Athiyandal and 875 µg g^{-1}Jawadhu hill (Fig. 2). Low-temperature stress manifested as an increase in antioxidant levels within the plant. Chilling stress caused internal water deficits, which in turn led to enhanced mannitol levels as part of plant's response to cold (18-21).

Effect of low temperature on yield components

The Panivaragu genotypes TNPm 280 and TNPm 282 recorded a greater 1000 grain weight (5.14 g), highest grain yield (1724 kg/ha) at CEM, Athiyandal and a grain yield 1475 kg/ha in the Jawadhu hills. The Panivaragu genotypes TNPm 280 and TNPm 282 performed well under low-temperature conditions. The TNPm 280 genotype showed that it took 43 days after sowing to reach 50 % flowering, which was earlier than that of the other genotypes. The HI was an important parameter for assessing total grain yield and dry weight and for evaluating the final crop output efficiency under low temperatures (22-26).

Table. 2 Effect of low temperature on morphological and yield components of Panivaragu at Jawadhu hill

Genotypes	Leaf Area (cm^2 plant^{-1})	Specific leaf weight (mg cm^{-2})	1000 grain weight (gm)	Days to 50 % flowering	Grain yield (kg/ha)	Harvest Index
TNPm 238	84.2	12.8	4.64	46.0	1156	41.5
TNPm 247	59.6	8.3	5.11	52.0	1102	41.5
TNPm 255	58.2	8.0	4.75	52.5	1084	43.0
TNPm 274	67.1	9.6	5.26	53.0	1191	45.5
TNPm 280	85.7	10.1	5.62	42.0	1475	47.0
TNPm 282	84.6	8.1	4.97	39.5	1382	45.5
ATL 1	69.7	9.2	5.09	42.5	1217	40.5
SEd	6.66	0.94	0.06	0.85	19.52	0.36
CD (P=0.05)	20.51	2.90	0.19	2.62	60.13	1.11



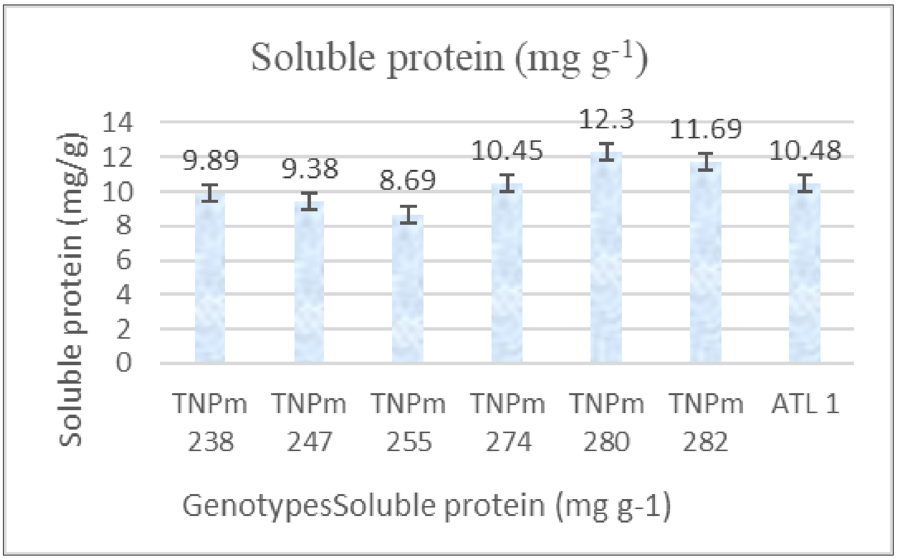


Fig. 1. Effect of low temperature on soluble protein (mg/g) in Panivaragu

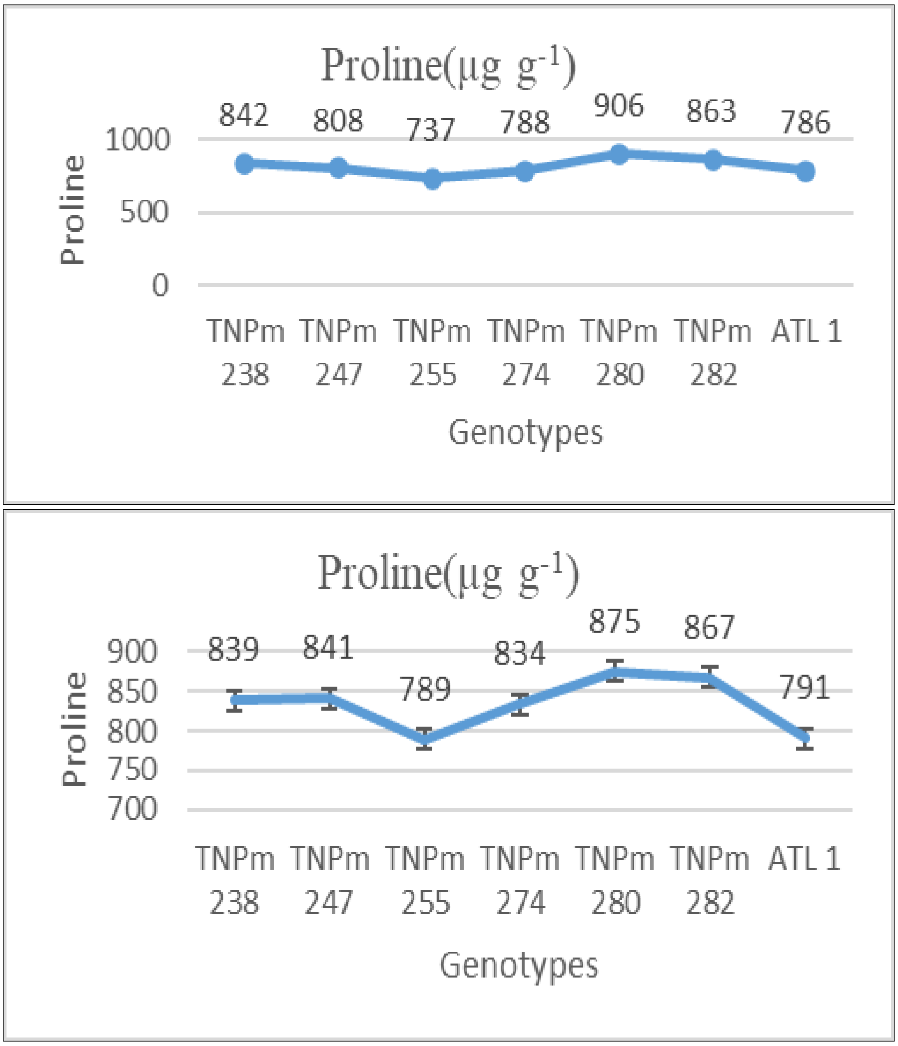


Fig. 2. Effect of low temperature on proline content (μg g^{-1}) in Panivaragu

Conclusion

Chilling injury was characterized by the rapid wilting of the leaves and the formation of water-soaked areas. The hill people cultivated a vast number of small millets. Even though it was a drought-tolerant crop, it did not tolerate cold temperatures. Plants' responses to low-temperature exposure had a significant impact on various growth parameters, such as leaf area, leaf area index, crop growth rate, relative water content, photosynthetic efficiency, days to 50 % flowering, number of tillers, number of grains per tiller, total dry matter production and yield.

In evaluating Panivaragu advanced cultures for low temperature tolerance, TNPm 280 and TNPm 282 had maximum leaf area, specific leaf weight, soluble protein content, 1000 grain weight and grain yield at 12 °C to 24 °C. Therefore these genotypes were good for *Rabi* cultivation, as they showed good tolerance to low temperature.

Authors' contributions

All authors contributed to the conceptualization and design of research, execution of field and laboratory experiments, data collection, analysis and interpretation of result and preparation of the manuscript.

Compliance with ethical standards

Conflict of interest: This research is original and the findings have neither been published nor are under consideration elsewhere. All the authors who contributed to the preparation of this manuscript declare that they have no conflict of interest.

Ethical issues: None

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