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Integrated Nutrient Management and Salicylic Acid Boost Quinoa (*Chenopodium quinoa* Willd.) Yield under Deficit Moisture Stress at Different Critical Stages

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Authors' contributions

This work was carried out in collaboration among all authors. Authors GPP, AB, SKD and BSR did the conceptualization, visualization, methodology, writing original draft. Authors GPP and SKD did the data curation, collection of review and literature survey, and authors DM, NP, KCS did the manuscript editing. All authors read and approved the final manuscript.

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ABSTRACT

Aims: A field study was conducted to quantify the effect of moisture deficit stress at different critical stages of quinoa and different mitigation approaches were adopted in order to alleviate moisture deficit stress.

Study Design: The experiment was designed in a split-plot design comprising six main plots (water management) and four subplots (stress mitigation approaches). The treatments in main plots viz., cut-off irrigation at branching (M_1), at ear formation (M_2), flowering (M_3), grain filling (M_4) stages, irrigating at all four stages (M_5) and irrigating as and when required (M_6), and subplot treatments viz., soil test-based fertiliser recommendation (STBFR) (S_1), STBFR + Salicylic acid spray at 100 ppm (S_2), STBFR + rice straw mulching (S_3) and integrated nutrient management (S_4) were tested.

Place and Duration of Study: The experiment was conducted at the Instructional Farm, Odisha University of Agriculture and Technology, Bhubaneswar during *Rabi* 2021-22.

Methodology: Moisture deficit stress was imposed by withholding irrigation water and not irrigating in the defined period. The treatments in the subplots were imposed as per the schedule.

Results: The lowest leaf area index was recorded when irrigation was withheld at the branching stage (0.61) which was statistically similar to M_2 (no irrigation at the ear formation stage) with an average leaf area index of 0.64. Similarly, plants under integrated nutrient management practices (S_4) recorded a significantly higher leaf area index (0.92) which was statistically at par with S_2 (STFBR + Salicylic acid spray) which was 0.87. The reduction in the TCC was the maximum when stress was applied at the branching and ear formation stage compared to the flowering and grain filling stage. The increment in grain yield by following INM (S_4) and STBFR+SA (S_2) under drought stress and irrigated control was 23.6% and 17.6%, respectively over fully inorganic nutrient management (S_1).

Conclusion: The result indicated that the branching stage is the most critical stage for irrigation in quinoa and integrated nutrient management could be the best approach under moisture deficit stress in quinoa among the other treatments.

Keywords: Quinoa; moisture deficit stress; salicylic acid; integrated nutrient management.

1. INTRODUCTION

Quinoa, scientifically known as Chenopodium quinoa Willd., is a highly nutritious crop indigenous to the Andean region, displaying significant potential for growth in diverse and challenging environments. Its nutritional excellence is driving its increasing popularity, as it provides a well-balanced profile of all nine essential amino acids. In India, quinoa is cultivated across 440 hectares, yielding an average of 1053 tonnes per year [1]. The shifting climate, marked by increased variability in weather patterns, encompassing alterations in precipitation, temperature extremes, and prolonged drought periods, has exacerbated the issue of moisture stress during critical phases of crop development. This challenge is of significant concern in agriculture, particularly in the context of climate change, as it disrupts the delicate equilibrium required for optimal crop growth. This disruption frequently results in moisture stress during vital growth stages, such as flowering and grain filling, leading to substantial reductions in crop yields. Notably, moisture stress in quinoa, primarily due to drought, has resulted in losses as high as 78.2% [2]. To mitigate the adverse impacts of moisture stress, several strategies have been developed. To address the adverse effects of moisture stress, a range of strategies has been devised. Salicylic acid, a naturally occurring plant hormone, shows promise in bolstering crop resilience to drought by activating diverse stress-responsive mechanisms. Alternatively, mulching can be employed to minimize soil water evaporation, thus maintaining consistent moisture levels. Integrated nutrient management techniques, involving precise nutrient application at various growth stages, have the potential to enhance a crop's ability to withstand moisture stress and continue thriving. In this context, a comprehensive approach that combines the application of Salicylic acid [3], mulching practices, and well-tailored integrated nutrient management (INM) offers a holistic approach to alleviating deficit moisture stress, improving crop resilience, and ensuring food security in an era marked by climate change-related challenges. This comprehensive strategy not only safeguards crop yields but also promotes sustainable agricultural practices in the face of an increasingly uncertain climate. The purpose of this experiment was to elucidate the best water management and deficit moisture mitigation strategies for higher quinoa production.

2. MATERIALS AND METHODS

A field experiment was carried out to know the effect of moisture deficit stress on the leaf area index, total chlorophyll content and grain yield of quinoa at Instructional Farm, OUAT, Bhubaneswar during Rabi of 2021-2022. The experiment was designed in a split-plot design comprising six main plots and four subplots with 24 treatment combinations with three replications. Main plots are cut-off irrigation at the branching stage (M_1), ear formation (M_2), flowering stage (M_3), flowering (M_4), irrigation at all four stages (M_5), and irrigation as and when required (M_6), and subplots are STBFR (S_1), STBFR + Salicylic acid (SA) @ 100 ppm (S_2), STBFR + Rice straw mulching @ 5 tonnes ha-1 (S_3), INM (S_4). The experimental site's soil had medium levels of available potassium (263 kg ha-1) and phosphorus (41.2 kg ha^{-1}) as well as low levels of organic carbon (4.9 kg ha^{-1}) and nitrogen (248 kg ha^{-1}). The crop received the recommended dosage of fertiliser (60:30:30 kg of N, P_2O_5, and K_2O). At each treatment (M_1, M_2, M_3, and M_4), a moisture deficit stress was induced by withholding irrigation for an appropriate duration of time. Irrigation was then given to remove the stress. Similarly, M5 and M6 received irrigation according to schedule. The subplot treatments were imposed as per the schedule.

Observations on plant height and relative water content were recorded at 20, 35, 50, and 65 days after sowing (DAS), and at harvest. Observation of LAI, total chlorophyll content was recorded at 20, 35, 50, and 65 DAS, and at harvest. The procedure for leaf area and chlorophyll estimation are given by [4]. The grain yield (kg ha^{-1}) was recorded after the harvest of the crop. The collected data were statistically analysed by standard analysis of variance technique for split-plot design as suggested by [5].

3. RESULTS AND DISCUSSION

The leaf area index recorded at different days of observations is provided in Table 1. There was a significant difference in the leaf area index recorded on different days of observations due to moisture deficit stress and different mitigation approaches. The leaf area index recorded at harvest in M_6 (1.08) was significantly higher among the different water management practices. The lowest leaf area index was recorded when irrigation was withheld at the branching stage (0.61) which was statistically similar to M_2 (no irrigation at the ear formation stage) with an average leaf area index of 0.64. Similarly, plants under integrated nutrient management practices (S_4) recorded a significantly higher leaf area index (0.92) which was statistically comparable to S_2 (STFBR + Salicylic acid spray) which was 0.87. The lowest (0.77) leaf area index was recorded in S_1 (STBFR) when compared to all other stress mitigation approaches.

The leaf area index varied significantly across different water management and stress mitigation approaches. The treatment M_6 had significantly higher LAI at harvest which was due to the continuous supply of water as and when required. But, plants under water stress i.e., M_1 to M_4 recorded relatively lower leaf area index compared to M_6, and maximum (43.5% and 40.7%) reduction was noticed in M_1 and M_2 i.e., moisture deficit stress at the branching stage and ear formation stage, respectively. The reduction was mainly due to moisture deficit stress subjected at the early stage of crop which would have inhibited the plants to grow taller. Besides, the total chlorophyll content is also reduced due to stress. The taller plants in M_5 and M_6 were due to a continuous supply of moisture. Similar results were obtained by [6].

The final leaf area index was influenced by different stress mitigation approaches. Significantly taller plants were observed when plants were subjected to integrated nutrient management and STBFR + application of Salicylic acid. The increase in leaf area index was 19.4% and 12.9% in S_4 and S_2, respectively, over S_1 (STBFR). The application of Salicylic acid with STBFR and integrated nutrition management were the causes of the rise in leaf area index. By enhancing the physical and chemical properties of the soil, the farm yard manure that was added in addition to inorganic fertilizer would have improved plant development under integrated nutrient management. Similarly, by acting as a growth regulator in both moisture shortage stress and irrigated conditions, the administration of Salicylic acid would have raised the leaf area index [6].

The total chlorophyll content recorded at different days of observation (Table 2) differed significantly due to different water management practices and stress mitigation approaches. On 20 DAS, the TCC of plants did not vary significantly due to different water management practices. On 35 DAS, M_1 (no irrigation at branching stage) had recorded significantly lower TCC (0.987 mg g^{-1}) which was statistically at par with M_2 (no irrigation at ear formation) with average TCC values (1.007 mg g^{-1}). A similar trend was observed on the rest if the days of observations i.e., lower values of TCC were recorded with M_1 (irrigation was not provided at the branching stage). The reduction due to stress at different critical stages of quinoa was in the order of greatest reduction at branching (27.3%) followed by ear formation (25.9%), flowering (19.4%), and grain filling (14.7%). On the other hand, among the different stress mitigation approaches, the treatment with INM recorded the higher total chlorophyll contents on all the days of observations, where STFBR + Salicylic acid spray stood next in place. Treatment S_1 (STBFR) recorded significantly lower values of TCC at all days of observations.

The total chlorophyll content of quinoa leaves in different treatments was influenced by the supply of irrigation water. It is worth noticing that, the moisture deficit stress at different crop growth stages had created the loss of turgidity in plant leaves. As a result, there was a decrement in the TCC. The reduction in the TCC was the maximum when stress was applied at the branching and ear formation stage compared to the flowering and grain filling stage. This might be due to the susceptibility of those stages of crops to moisture deficit conditions which ultimately reflected in terms of a decrease in TCC of quinoa leaves. Susceptibility to moisture stress at the early stage of crops is well documented by [7,8].

Table 1. Effect of different water management and stress mitigation approaches on the leaf area index of quinoa

Water management	20 DAS	35 DAS	50 DAS	65 DAS	At harvest
M_1: No irrigation at branching	0.44	0.64	1.72	1.72	0.61
M_2: No irrigation at ear formation	0.42	0.65	1.81	1.81	0.64
M_3: No irrigation at flowering	0.45	0.76	2.16	2.16	0.76
M_4: No irrigation at grain filling	0.47	0.80	2.56	2.56	0.90
M_5: Irrigation at all above four stages	0.47	0.79	2.92	2.92	1.05
M_6: Irrigation as and when required	0.48	0.82	2.96	2.96	1.08
SEm(±)	0.017	0.027	0.086	0.086	0.012
CD (5%)	0.05	0.09	0.27	0.27	0.04
Stress mitigation approaches					
S_1: STBFR	0.44	0.67	2.18	2.18	0.77
S_2: STBFR + Salicylic acid	0.43	0.74	2.42	2.42	0.87
S_3: STBFR + Rice straw mulching	0.45	0.73	2.28	2.28	0.80
S_4: INM (75%N inorganic + 25%N FYM)	0.51	0.83	2.53	2.53	0.92
SEm(±)	0.009	0.015	0.047	0.047	0.017
CD (5%)	0.03	0.04	0.13	0.13	0.05

Table 2. Effect of different water management and stress mitigation approaches on the total chlorophyll content (mg g^{-1} fresh weight of leaf) of quinoa

Water management	20 DAS	35 DAS	50 DAS	65 DAS	At harvest
M_1: No irrigation at branching	0.867	0.987	1.050	1.106	0.952
M_2: No irrigation at ear formation	0.852	1.007	1.077	1.141	0.983
M_3: No irrigation at flowering	0.854	1.344	1.528	1.147	1.019
M_4: No irrigation at grain filling	0.856	1.350	1.868	1.090	0.935
M_5: Irrigation at all above four stages	0.865	1.361	1.851	1.274	1.071
M_6: Irrigation as and when required	0.865	1.359	1.897	1.278	1.062
SEm(±)	0.013	0.018	0.023	0.017	0.015
CD (5%)	NS	0.056	0.072	0.054	0.048
Stress mitigation approaches					
S_1: STBFR	0.846	1.181	1.506	1.116	0.963
S_2: STBFR + Salicylic acid	0.859	1.259	1.561	1.197	1.015
S_3: STBFR + Rice straw mulching	0.862	1.222	1.539	1.150	0.991
S_4: INM (75% Inorganic + 25% FYM)	0.872	1.277	1.575	1.227	1.047
SEm(±)	0.009	0.011	0.016	0.023	0.009
CD (5%)	0.026	0.032	0.046	0.065	0.027

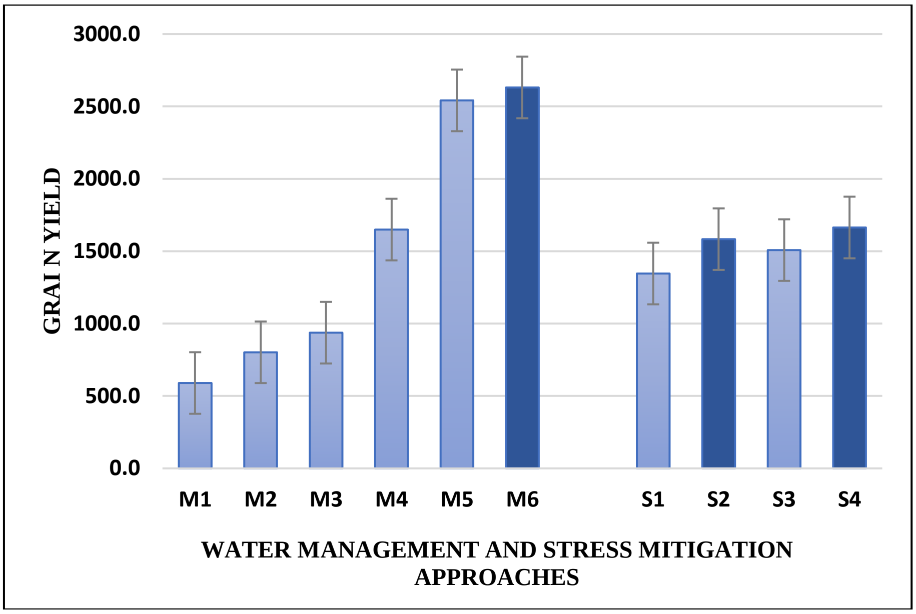

Fig. 1. Effect of different water management and stress mitigation approaches on the grain yield (kg ha^{-1}) of quinoa

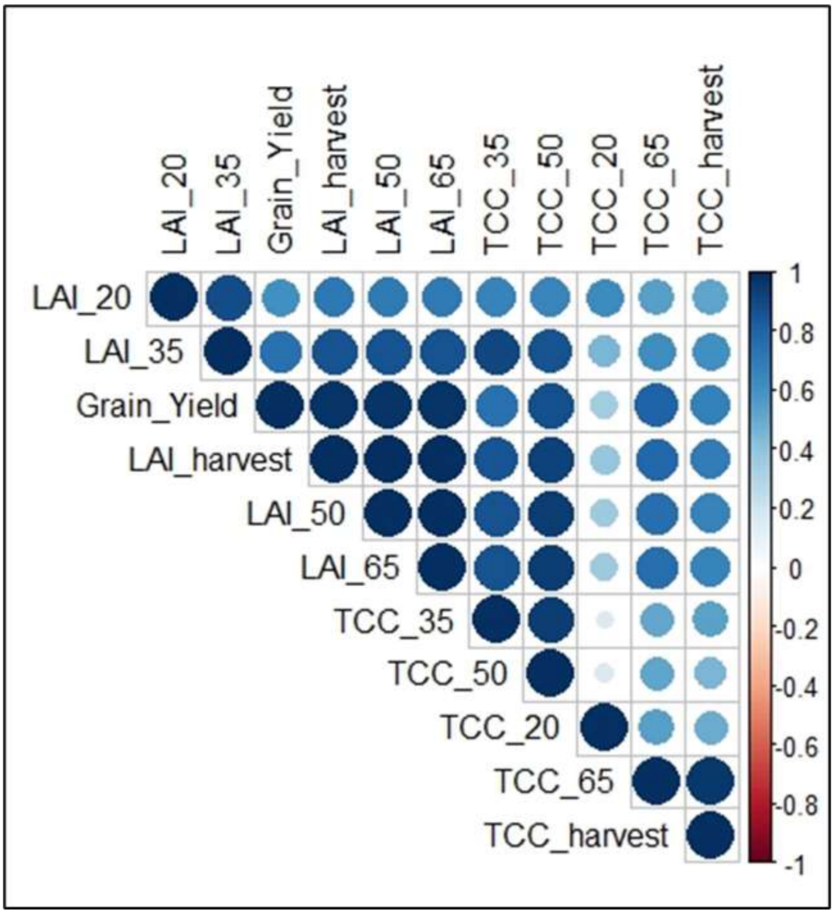

Fig. 2. Correlation heat matrix of different traits

Among the various mitigation approaches, the integrated nutrient management recorded higher values of TCC compared to other treatments. The integration of organic and inorganic forms of nutrients would have reduced the susceptivity of the crop during stress and increased tolerance to a decrease in total chlorophyll content, unlike other treatments except in S_2 i.e., application of SA along with STBFR during the crop period. Salicylic acid had a positive impact in the crop’s total chlorophyll content under water deficit stress. It could able to maintain cellular turgidity by maintaining osmotic balance in the plant cell during drought stress thereby improving the chlorophyll content in the leaf tissue. Similar results were obtained by various workers [3, 9,10].

The grain yield significantly varied among the different water management and stress management approaches (Fig. 1). The treatment with no irrigation at branching (M_1) recorded the lowest (589 kg ha^{-1}) grain yield and treatment M_6 recorded a significantly higher grain yield (2631 kg ha^{-1}) among the various water management practices. Among the different stress mitigation tactics, S_4 (integrated nutrient management) was able to produce a statistically higher (1663 kg ha^{-1}) grain yield which was followed by S_2 (STFBR + Salicylic acid spray) [11,12].

Growth characteristics such as cellular water content and leaf area index influence grain yield. When moisture deficit stress was introduced during several crop growth phases, such as branching, ear formation, flowering, and grain filling stages, grain production dropped (70.6%, 69.5%, 60.3%, and 31.3%, respectively). The decrease in grain yield was due to reduced leaf area index and reduced total chlorophyll content. The early stage of the crop is more susceptible to drought stress as the no irrigation at the early stage of growth could have reduced the sink formation capacity and ultimately led to lesser grain yield. There was a positive correlation between grain yield leaf area index and total chlorophyll content at different stages of the crop (Fig. 2). On the other hand, the increment in grain yield by following INM (S_4) and STBFR + Salicylic acid (S_2) under drought stress and irrigated control was 23.6% and 17.6%, respectively over fully inorganic nutrient management (S_1). The beneficial aspects of Salicylic acid and integrated nutrient management on crop yield were given by [13,14].

4. CONCLUSION

Based on the conducted experiment, it can be inferred that moisture deficit stress adversely impacts the leaf area index, total chlorophyll content, and grain yield during various growth stages of quinoa. Notably, the negative effects are more pronounced during the branching and ear formation stage compared to other stages. In terms of stress mitigation strategies, employing integrated nutrient management and applying Salicylic acid in accordance with soil test-based fertilizer recommendations yielded more favourable outcomes compared to the other two treatments.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Srinivasa Rao K. Sarikotha panta quinoa, Sakhi News. 10 on 11.08.2015.
2. Telahigue DC, Yahia LB, Aljane F, Belhouchett K, Toumi L. Grain yield, biomass productivity and water use efficiency in quinoa (*Chenopodium quinoa* Willd.) under drought stress. J of Scientific Agric. 2017;1:222-32.
3. Najafabadi MY, Ehsanzadeh P. Salicylic acid effects on osmoregulation and seed yield in drought-stressed sesame. Agron. J. 2017;109(4):1414-22. Available:https://doi.org/10.2134/agronj2016.11.0655
4. Gomez KA and Gomez AA. Statistical procedures for agricultural research Vol. 2nd Ed. New Delhi, India: Wiley India Pvt Ltd.; 2010.
5. Saddiq MS, Wang X, Iqbal S, Hafeez MB, Khan S, Raza A, Iqbal J, Maqbool MM, Fiaz S, Qazi MA, Bakhsh A. Effect of water stress on grain yield and physiological characters of quinoa genotypes. Agron. 2021;11(10):1934. Available:https://doi.org/10.3390/agronomy11101934
6. Sun Y, Liu F, Bendevis M, Shabala S, Jacobsen SE. Sensitivity of two quinoa (*Chenopodium quinoa* Willd.) varieties to progressive drought stress. J. Agron. Crop Sci. 2014;200(1):12-23. Available:https://doi.org/10.1111/jac.12042
7. Patnaik GP, Monisha V, Thavaprakaash N, Djanaguiraman M, Sachin S, Vikram K,

Girwani T, Jeeva M, Monicaa M, Patnaik L, Behera B. Selenium Application Improves Drought Tolerance during Reproductive Phase of Rice. Sustainability. 2023; 15(3):2730. Available:https://doi.org/10.3390/su15032730

8. Singh B, Usha K. Salicylic acid induced physiological and biochemical changes in wheat seedlings under water stress. Plant Growth Regul. 2003;39:137-41. Available:https://doi.org/10.1023/A:1022556103536
9. Bandurska H, Stroi ski A. The effect of salicylic acid on barley response to water deficit. Acta Physiologiae Plantarum. 2005;27:379-86. Available:https://doi.org/10.1007/s11738-005-0015-5
10. Salama AM, Seleem E, Abd El Salam R, Ghoniem A. Response of quinoa plant grown under drought stress to foliar application with salicylic acid, paclobutrazol and algae extract. J. Agric. Sci. 2021;3(2):87-104. Available:https://doi.org/10.21608/sjas.2021.81529.1118
11. Patnaik GP, Thavaprakaash N, Djanaguiraman M. Effect of Period of Soil Moisture Stress at Panicle Initiation and Flowering Stages on Nutrient Uptake and Post-Harvest Soil Nutrient Status in Rice. Madras Agric. J. 2020 11;107(7-9):1-6. Available:https://doi.org/10.29321/MAJ.2020.000377
12. Sachin S, Thavaprakaash N, Djanaguiraman M, Patnaik GP. Effect of induced moisture stress at critical stages on physiological traits and yield of rice (*Oryza sativa* L.). J. Agromet. 2023 25;25(2):268-73. Available:https://doi.org/10.54386/jam.v25i2.2043
13. Patnaik, G.P., N. Thavaprakaash, M. Djanaguiraman. Effect of moisture stress at critical stages on growth and relative water content of rice (*Oryza sativa*). In Extended Summaries: 5th International Agronomy Congress. 2021;2:1037-1038.
14. Yang A, Akhtar SS, Amjad M, Iqbal S, Jacobsen SE. Growth and physiological responses of quinoa to drought and temperature stress. J. Agron. Crop Sci. 2016;202(6):445-53. Available:https://doi.org/10.1111/jac.12167

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