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Shubham Ahirwar
Ph.D Research Scholar, Department of Horticulture, College of Agriculture, JNKVV, Jabalpur, Madhya Pradesh, India

Reena Nair
Assistant Professor, Department of Horticulture, College of Agriculture, JNKVV, Jabalpur, Madhya Pradesh, India

SK Pandey
Professor and Head, Department of Horticulture, College of Agriculture, JNKVV, Jabalpur, Madhya Pradesh, India

Manoj K Awasthi
Professor and Head, Department of Soil and Water Engineering, College of Agricultural Engineering, JNKVV, Jabalpur, Madhya Pradesh, India

R Shiv Ramakrishnan
Assistant Professor, Department of Plant Physiology, College of Agriculture, JNKVV, Jabalpur, Madhya Pradesh, India

Surabhi Jain
Scientist (Statistic), PC Unit, AICRP on Sesame and Niger, College of Agriculture, JNKVV, Jabalpur, Madhya Pradesh, India

Corresponding Author:
Shubham Ahirwar
Ph.D Research Scholar, Department of Horticulture, College of Agriculture, JNKVV, Jabalpur, Madhya Pradesh, India

Quality response of Nigella (*Nigella sativa* L.) to varying IW/CPE irrigation levels and mulching applications

Shubham Ahirwar, Reena Nair, SK Pandey, Manoj K Awasthi, R Shiv Ramakrishnan and Surabhi Jain

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Abstract

A field experiment was conducted at the College of Agriculture, JNKVV, Jabalpur, to assess the interactive effects of irrigation levels and mulching practices on the seed quality of *Nigella sativa*. The study employed a split-plot design with four irrigation regimes based on IW/CPE ratios (1.0, 0.8, 0.6, 0.4) as main plots and four mulching practices—black polythene, silver-black polythene, organic mulch, and without mulch—as subplots, resulting in 16 treatment combinations (T_1-T_{16}). The highest essential oil content (2.13%) and fat percentage (32.24%) were recorded under T_{16} (0.4 IW/CPE + without mulch), followed by T_{15} (2.04% oil, 32.09% fat; 0.4 IW/CPE + organic mulch) and T_{13} (1.96% oil, 30.67% fat; 0.4 IW/CPE + black polythene mulch), indicating that moderate deficit irrigation enhances secondary metabolite accumulation. Conversely, the lowest oil (1.08%) and fat (25.79%) were observed under T_2 (1.0 IW/CPE + silver-black mulch) and T_6 (0.8 IW/CPE + silver-black mulch). Test weight was highest under T_2 (2.69 g), T_1 (2.57 g; 1.0 IW/CPE + black mulch), and T_6 (2.49 g), highlighting the positive effect of optimum irrigation with reflective mulches on seed filling. Overall, regulated deficit irrigation at 0.4 IW/CPE combined with organic or black polythene mulch maximizes biochemical seed quality, while higher irrigation (0.8-1.0 IW/CPE) with silver-black mulch ensures superior seed boldness, offering practical strategies to enhance both nutraceutical and commercial value of *Nigella sativa*.

Keywords: *Nigella sativa*, irrigation levels, IW/CPE ratio, mulching, essential oil, fat content, test weight, seed quality, deficit irrigation, split-plot design

Introduction

Nigella (*Nigella sativa* L.), commonly known as black cumin or kalonji, is an annual herbaceous plant belonging to the family Ranunculaceae and native to Mediterranean and western Asia regions (D'Antuono *et al*. 2002) [8]. It is widely recognized for its multifaceted uses as a medicinal and aromatic seed spice. The seeds of Nigella contain significant amounts of fixed oil (28-36%), volatile oil (0.4-2.5%), proteins (20-30%), and carbohydrates, in addition to bioactive constituents such as thymoquinone, nigellone, and unsaturated fatty acids (Abdou *et al*., 2023) [1]. These biochemical compounds contribute to its high therapeutic value, including antioxidant, antimicrobial, anti-inflammatory, and anticancer activities, making Nigella seeds an important raw material for pharmaceuticals, neutraceuticals, and functional foods (Rahim *et al*., 2022) [18]. Owing to its unique flavor and medicinal efficacy, the global demand for Nigella seeds has increased steadily, creating new opportunities for enhancing its production and quality through scientific crop management. Despite its economic and medicinal significance, Nigella cultivation is often constrained by water scarcity, especially in semi-arid and arid regions where it is primarily grown. Water stress directly affects plant growth, seed filling, and biochemical quality traits such as oil content, fatty acid composition, and thymoquinone concentration. Several studies have confirmed that drought stress reduces essential oil yield and alters fatty acid profiles, particularly lowering the proportion of unsaturated fatty acids such as linoleic and oleic acids (Abdou *et al*., 2023) [1]. Consequently, irrigation scheduling emerges as a key agronomic intervention to sustain productivity and ensure desirable quality attributes. Irrigation water to cumulative pan evaporation (IW/CPE) ratio is a well-established method for scientific irrigation scheduling. It matches irrigation supply with atmospheric evaporative demand, thereby optimizing crop water use efficiency (Senyigit and Arslan 2018) [19]. In seed spices such as fennel (*Foeniculum vulgare*) and cumin (*Cuminum cyminum*), drip irrigation scheduled at IW/CPE ratios ranging from 0.8 to 1.0 has been reported to maximize yield and enhance oil content, test weight, and seed germination traits (Ghiyal *et al*., 2024) [10]. In turmeric (Curcuma longa), drip irrigation at 0.8 IW/CPE coupled with mulching improved curcumin and oleoresin content, demonstrating that precise irrigation scheduling not only increases productivity but also enhances quality attributes (Kaur and Brar 2016) [15]. However, while similar approaches are expected to benefit Nigella, empirical studies specifically evaluating quality responses under varying IW/CPE-based irrigation levels remain scarce. In addition to irrigation, mulching is another critical practice that influences crop microclimate, soil water retention, and nutrient dynamics. Mulches whether plastic (silver-black polythene or black polythene) or organic (crop residues, straw, compost) reduce evaporation losses, suppress weed growth, and regulate soil temperature (Demo and Bogale 2024) [9]. In spice crops, mulching has shown remarkable effects; for example, in fennel, black polythene mulch improved seed oil content and water use efficiency, while in turmeric, mulching under drip irrigation substantially enhanced quality parameters (Kaur and Brar 2016) [15]. Mulching also facilitates better nutrient uptake and soil microbial activity, indirectly contributing to improved biochemical quality. Recent investigations into Nigella quality under different soil and water management practices highlight the crop's sensitivity to stress and management interventions. Abdou *et al*. (2023) [1] demonstrated that compost application under drought stress significantly improved seed yield, fixed oil content, and fatty acid composition, indicating that soil amendments can buffer against quality deterioration caused by water deficit. Similarly, biochar and conservation tillage practices were found to improve agronomic performance and fatty acid composition of Nigella, enhancing linoleic and oleic acid concentrations under limited moisture conditions (Kiani *et al*., 2024) [16]. Another study by Chaudhary *et al*. (2025) [7] reported that organic amendments not only improved seed oil content but also enhanced soil fertility, thereby sustaining productivity under resource-constrained environments. These findings emphasize that both water management and soil environment strongly regulate Nigella's quality parameters. Despite this body of evidence, there is a clear knowledge gap regarding the combined effects of IW/CPE-based irrigation levels and mulching practices on Nigella quality attributes. Existing studies have primarily addressed either irrigation or soil amendments separately, and most focused on yield or morphological parameters rather than detailed biochemical traits such as fixed oil content and seed fat percentage. Given the increasing importance of Nigella in medicinal and food industries, there is a pressing need to evaluate how integrated water and mulch management strategies influence its quality. Therefore, the present investigation entitled "Quality Response of Nigella (*Nigella sativa* L.) to Varying IW/CPE Irrigation Levels and Mulching Applications" was undertaken to fill this gap. The objective of the study is to examine how different drip irrigation levels based on IW/CPE ratios, in combination with mulching applications, influence the quality attributes of Nigella under semi-arid conditions. The findings are expected to provide scientific insights for improving Nigella production systems by enhancing seed quality while ensuring efficient water use.

2. Materials and Methods

The field experiment was conducted during the *Rabi* seasons of 2023-24 at the Vegetable Research Centre, Maharajpur, Department of Horticulture, Jawaharlal Nehru Krishi Vishwavidyalaya, Jabalpur, Madhya Pradesh, India located in the central part of Madhya Pradesh, India, lies between 23.16°N latitude and 79.95°E longitude, at an elevation of approximately 412 meters above sea level. The site experiences a subtropical climate with hot summers, a distinct monsoon season, and cool winters. The average annual rainfall of the region is approximately 1200 mm, mostly received during June to September, while the *Rabi* season is largely dependent on irrigation. Meteorological observations, including rainfall, temperature, evaporation, and relative humidity, were recorded from the Indian Meteorological Department, Adhartal, Jabalpur, during the crop season. The experiment was laid out in a split-plot design with three replications, assigning four irrigation levels to the main plots and four mulch types to the subplots, thereby creating sixteen treatment combinations. Irrigation levels were based on IW/CPE ratios of 1.0 (I1), 0.8 (I2), 0.6 (I3), and 0.4 (I4), while the mulching treatments included black polythene mulch (M1), silver-black polythene mulch (M2), organic mulch (M3), and no mulch (M4). The treatments were thus designated as I1M1 to I4M4. The details of treatments are presented in Table 1.

Tables 1: Details of Treatments

Treatments	Combinations
T_1	1.0 IW/CPE + Black Polythene mulch
T_2	1.0 IW/CPE + Silver Black Polythene mulch
T_3	1.0 IW/CPE + Organic mulch
T_4	1.0 IW/CPE + without mulch
T_5	0.8 IW/CPE + Black Polythene mulch
T_6	0.8 IW/CPE + Silver Black Polythene mulch
T_7	0.8 IW/CPE + Organic mulch
T_8	0.8 IW/CPE + without mulch
T_9	0.6 IW/CPE + Black Polythene mulch
T_{10}	0.6 IW/CPE + Silver Black Polythene mulch
T_{11}	0.6 IW/CPE + Organic mulch
T_{12}	0.6 IW/CPE + without mulch
T_{13}	0.4 IW/CPE + Black Polythene mulch
T_{14}	0.4 IW/CPE + Silver Black Polythene mulch
T_{15}	0.4 IW/CPE + Organic mulch
T_{16}	0.4 IW/CPE + without mulch

A uniform irrigation depth of 50 mm was applied at each irrigation, with the frequency regulated based on the IW/CPE ratio. Mulching treatments were imposed immediately after sowing: M_1 with 25 µ thick black polyethylene, M_2 with 25 µ thick silver-black polyethylene, and M_3 with crop residues applied at a thickness of about 5 cm, while M_4 served as the control without mulch. The experimental soil was medium black (Vertisols), slightly alkaline in reaction (pH 7.6), with medium organic carbon content (0.56%), low available nitrogen, medium phosphorus, and high potassium levels. It was well-drained and exhibited good water-holding capacity, making it suitable for Nigella cultivation. Each experimental plot measured 7.0 × 2.4 m, and the crop was planted at a spacing of 30 cm × 15 cm. Nigella variety 'Ajmer Nigella-20' was sown in the second fortnight of November using a uniform seed rate of 10 kg ha^{-1}. The recommended dose of fertilizers (40:20:20 kg NPK ha^{-1}) was applied, with half nitrogen and full phosphorus and potassium as basal, and the remaining nitrogen top-dressed at 30 days after sowing. Intercultural operations such as thinning, weeding, and hoeing were performed as per requirement, and uniform crop protection measures were adopted. Irrigation scheduling was done using a Class A pan evaporimeter installed at the meteorological observatory of the Indian Meteorological Department, Adhartal, Jabalpur. Soil moisture status before irrigation was monitored to ensure treatment accuracy.

Observations at harvest focused on seed quality attributes, particularly essential oil content and fat percentage, which are critical determinants of Nigella seed quality. For essential oil estimation, 50 g of finely crushed Nigella seeds were subjected to hydro-distillation using a Clevenger-type apparatus for 3 hours, following AOAC (2016) standard procedures. In this method, volatile compounds were distilled with water vapor and condensed in the apparatus, allowing the essential oil to separate and collect in a graduated tube. The volume of oil obtained was measured and expressed as a percentage of the seed weight, providing a reliable estimate of essential oil content. For determination of fat content, 5 g of air-dried, finely ground seed sample was placed in a Soxhlet extraction unit and continuously extracted with petroleum ether (boiling point 60-80 °C) for 6-8 hours. After extraction, the solvent was evaporated using a rotary evaporator, and the residue containing oil was oven-dried to a constant weight. The weight of the extracted oil was then expressed as a percentage of the original seed sample, representing the crude fat content. Both methods ensured accuracy and reproducibility of results, allowing precise assessment of Nigella seed biochemical quality under different irrigation and mulching treatments. Observations on seed physical quality were also recorded in terms of test weight (1000-seed weight). For this, a random seed sample was drawn from each treatment and 1000 seeds were manually counted and weighed using a precision electronic balance. The weight was expressed in grams (g) as per the standard rules of the International Seed Testing Association (ISTA, 2015). Test weight served as an indicator of seed boldness, maturity, and density, which are closely associated with overall quality and market acceptability of Nigella seeds. The data analyzed statistically using analysis of variance (ANOVA) for a split-plot design following Gomez and Gomez (1984), and treatment means were compared using the least significant difference (LSD) at a 5% probability level.

3. Results and Discussion

Quality traits such as essential oil content, seed fat percentage, and test weight are critical determinants of the neutraceuticals, medicinal, and commercial value of Nigella sativa. These parameters are highly sensitive to the crop's growing environment, particularly soil moisture status and microclimatic modifications through mulching. Adequate irrigation scheduling, based on IW/CPE ratios, ensures a favorable soil-water balance that facilitates efficient nutrient uptake and accelerates various metabolic processes, including oil biosynthesis and carbohydrate translocation, thereby influencing both oil and fat accumulation in the seeds. Similarly, mulching practices not only conserve soil moisture and moderate temperature fluctuations but also enhance the seed filling process, ultimately improving test weight and seed quality. In the present investigation, the interaction of irrigation levels and mulching practices played a decisive role in regulating the biochemical composition and seed boldness of nigella, indicating that optimized water supply and appropriate mulching can significantly enhance the intrinsic quality attributes of the crop. The detailed results and their interpretation are discussed in the subsequent section.

3.1 Essential Oil Content

The essential oil content of *Nigella sativa* seeds varied significantly among treatments, with values ranging from 1.08% to 2.13% which is clearly evident from the data presented in Table 2 and corresponding graphical representation in Figure 1. The maximum oil concentration (2.13%) was observed in T_{16} (0.4 IW/CPE + without mulch), closely followed by T_{15} (2.04%) and T_{12} (1.96%). These treatments were statistically superior, as differences above the CD value (0.10) were significant. Interestingly, moderate deficit irrigation (0.4 IW/CPE) consistently enhanced essential oil accumulation irrespective of mulch type, while the combination with organic mulch (T_{15}) and without mulch (T_{16}) proved most effective. The likely reason is that reduced irrigation frequency imposed mild water stress, which stimulates the biosynthesis of secondary metabolites such as essential oils (Abdou *et al*., 2023) [1]. Additionally, organic mulching may have improved soil microbial activity and nutrient mineralization, thereby supporting oil biosynthesis, whereas absence of mulch (T_{16}) possibly induced slightly higher stress, further enhancing oil accumulation. Similar responses of increased essential oil concentration under deficit irrigation have been reported in fennel and cumin (Kiani *et al*. 2024) [16]. By contrast, the lowest oil content (1.08%) was recorded in T_2 (1.0 IW/CPE + silver-black mulch), followed by T_1 (1.30%) and T_6 (1.32%), where full or near-full irrigation levels restricted oil synthesis. Ample water supply under these treatments likely promoted vegetative growth at the expense of secondary metabolite accumulation. This negative relationship between high water availability and essential oil concentration has also been documented in coriander and caraway. Hadi *et al*. (2012) [13] found that seed yield reduced but essential oil as well as thymoquinone and carvone contents increased under drought conditions. Bourgou *et al*. (2010) [6] also noted that seed yield decreased but essential oil contents increased in black cumin under salinity stress. According to Mozzafari *et al*. (2000) [17], reducing irrigation improved the oil content of black cumin seeds, indicating its moderate adaptability to water stress. Thus, it is evident that deficit irrigation levels (0.4-0.6 IW/CPE) are more conducive to oil accumulation in Nigella sativa compared to full irrigation regimes.

3.2 Fat percent

Seed fat content followed a trend similar to that of essential oil, with values ranging from 25.79% to 32.24%. The data are presented in Table 2 and illustrated graphically in Figure 1. The highest fat percentage was obtained under T_{16} (32.24%), T_{15} (32.09%), and T_{13} (30.67%), all of which correspond to the lowest irrigation regime (0.4 IW/CPE). The CD value of 0.63 confirmed that these treatments were significantly superior to others, while the very low CV

(1.31%) indicated high precision of the results. The improvement in fat content under deficit irrigation may be attributed to enhanced assimilate partitioning towards seed storage compounds, as plants under mild stress tend to accumulate more lipids for energy conservation (Bhattacharya, 2022) [5]. Organic mulch (T_{15}) further improved fat content, likely due to its role in enhancing soil organic matter and nutrient availability, while the absence of mulch in T_{16} may have amplified stress conditions, thus maximizing lipid biosynthesis. On the other hand, the lowest fat content (25.79%) was observed under T_6 (0.8 IW/CPE + silver-black mulch), followed by T_2 (26.23%). According to Benakashani *et al*. (2025) [4] growing black cumin under a berseem clover living mulch (with mowing after establishment) resulted in a 12.4% increase in oil yield over the weed-free control. Additionally, the quality of oil was improved, as reflected in a 3.47% increase in unsaturated fatty acids and a 13.35% improvement in the unsaturated-to-saturated fatty acid ratio. Thus, the living mulch system provided simultaneous benefits in terms of yield and oil quality. Both treatments combined higher irrigation levels with silver-black mulch, which may have reduced soil temperature fluctuations but simultaneously suppressed beneficial stress-induced metabolic activity. These results suggest that variations in essential oil yield and composition of black cumin may largely depend on the irrigation practices. Excess irrigation at these levels likely promoted carbohydrate partitioning into structural growth rather than storage lipids.

The present findings clearly demonstrate that both essential oil content and fat percentage of nigella seeds were markedly influenced by irrigation levels and mulching practices. The highest values for essential oil (2.13%) and fat (32.24%) were consistently obtained under 0.4 IW/CPE irrigation regime, particularly when combined with black polythene mulch (T_{13}) or organic mulch (T_{15}), as well as without mulch (T_{16}). This suggests that moderate deficit irrigation coupled with suitable mulching creates a favorable microclimate that promotes secondary metabolite synthesis and assimilate partitioning toward storage lipids. In contrast, higher irrigation levels (1.0 and 0.8 IW/CPE) in combination with silver-black mulch recorded the lowest oil and fat content, likely due to excessive vegetative growth and reduced stress-induced metabolite accumulation. According to Bayati 2020 the highest essential oil content was noted in 'Shahrekord' under the three irrigation regimes exercised while the lowest levels were obtained in 'Syria' under I1 and in 'Afghanistan' under both I2 and I3. The statistical robustness of the results, as reflected by the low CV values and significant CD, further strengthens the reliability of these conclusions. Overall, the results indicate that regulated deficit irrigation at 0.4 IW/CPE with organic or black polythene mulching can be recommended as the most efficient management practice for enhancing seed quality in nigella, leading to higher oil and fat concentration without compromising crop performance.

Table 2: Effect of irrigation levels and mulching practices on essential oil content and fat% of Nigella Seeds.

	Treatments	Essential oil content (%)	Fat%
T_1	1.0 IW/CPE + Black Polythene mulch	1.30^{g}	27.01^{f}
T_2	1.0 IW/CPE + Silver Black Polythene mulch	1.08^{h}	26.23^{g}
T_3	1.0 IW/CPE + Organic mulch	1.48^{f}	27.28^{ef}
T_4	1.0 IW/CPE + without mulch	1.58^{ef}	28.60^{d}
T_5	0.8 IW/CPE + Black Polythene mulch	1.49^{f}	27.07^{f}
T_6	0.8 IW/CPE + Silver Black Polythene mulch	1.32^{g}	25.79^{g}
T_7	0.8 IW/CPE + Organic mulch	1.57^{ef}	27.81^{e}
T_8	0.8 IW/CPE + without mulch	1.72^{cd}	28.75^{cd}
T_9	0.6 IW/CPE + Black Polythene mulch	1.66^{f}	28.87^{cd}
T_{10}	0.6 IW/CPE + Silver Black Polythene mulch	1.49^{f}	27.84^{e}
T_{11}	0.6 IW/CPE + Organic mulch	1.81^{c}	30.48^{b}
T_{12}	0.6 IW/CPE + without mulch	1.96^{b}	30.07^{a}
T_{13}	0.4 IW/CPE + Black Polythene mulch	1.75^{cd}	30.67^{b}
T_{14}	0.4 IW/CPE + Silver Black Polythene mulch	1.56^{ef}	29.35^{c}
T_{15}	0.4 IW/CPE + Organic mulch	2.04^{ab}	32.09^{a}
T_{16}	0.4 IW/CPE + without mulch	2.13^{a}	32.24^{a}
S.Em±		0.04	0.22
C.D. (at 5%)		0.1	0.63
CV		3.76	1.31

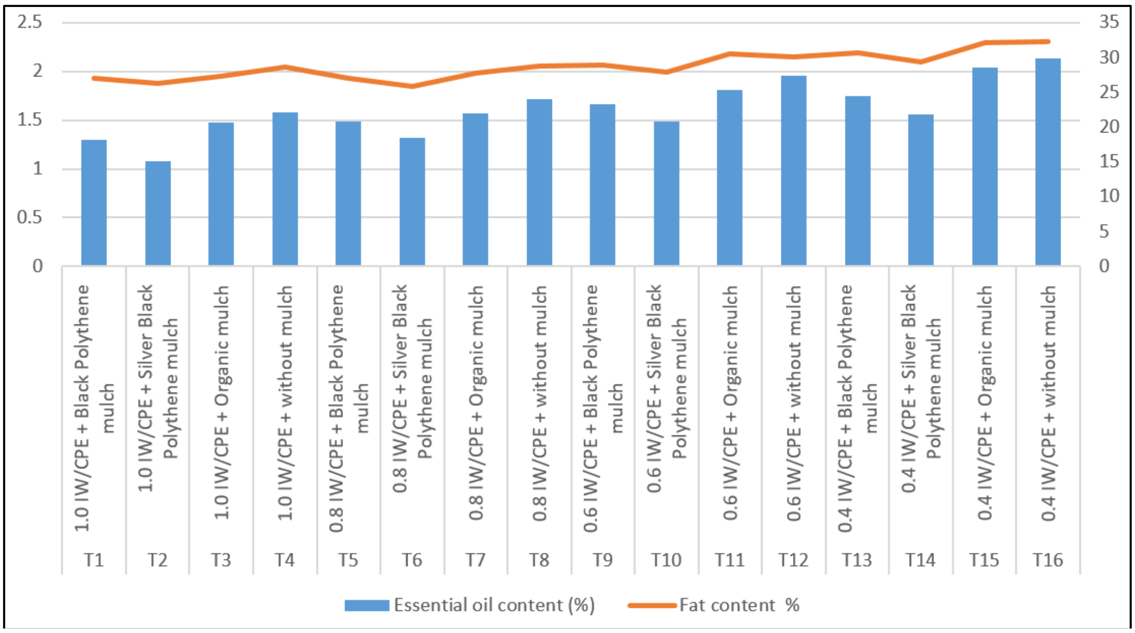

Fig 1: Effect of irrigation levels and mulching practices on essential oil content and fat% of Nigella Seeds.

3.3 Test Weight (1000-seed weight)

The test weight of Nigella sativa seeds was significantly affected by different irrigation levels and mulching practices which is clearly evident from the data presented in Table 3 and corresponding graphical representation in Figure 2. The highest test weight (2.69 g) was recorded in T_2 (1.0 IW/CPE + silver-black polythene mulch), which was statistically comparable with T_1 (1.0 IW/CPE + black mulch; 2.57 g) and T_6 (0.8 IW/CPE + silver-black mulch; 2.49 g). These results highlight the positive role of optimum irrigation coupled with reflective mulches in enhancing seed boldness and density. Silver-black mulch likely maintained favorable hydrothermal regimes around the root zone, improving assimilate translocation and seed filling, ultimately leading to heavier seeds. Similar improvements in seed physical traits under optimum irrigation and mulching have also been reported in Nigella and other spice crops (Abdou *et al*., 2023) [1]. In contrast, the lowest test weight (1.89 g) was obtained under T_{16} (0.4 IW/CPE + without mulch), closely followed by T_{12} (0.6 IW/CPE + without mulch; 1.96 g) and T_{15} (0.4 IW/CPE + organic mulch; 1.99 g). These treatments, being under moisture stress with no protective mulch, failed to maintain adequate seed filling, resulting in shriveled and lighter grains. Earlier studies have confirmed that severe water stress reduces seed weight in *Nigella sativa* due to impaired carbohydrate partitioning and incomplete seed development (Mozaffari *et al*., 2000) [17]. This is consistent with the concept that deficit irrigation, while sometimes improving essential oil concentration, often compromises physical quality traits such as seed size and test weight (Gutierrez, 2017) [12]. The statistical analysis supported these trends, with the critical difference (CD) at 5% level (0.17 g) validating significant treatment differences, while the relatively low coefficient of variation (CV = 4.42%) indicated good experimental precision. Overall, the findings suggest that maintaining irrigation at 0.8-1.0 IW/CPE ratio with silver-black or black mulch ensures superior seed boldness and quality, whereas severe deficit irrigation (0.4 IW/CPE) without mulch is highly detrimental to seed physical attributes.

Table 3: Effect of irrigation levels and mulching practices on Test Weight (g) of Nigella Seeds.

Treatments		Test Weight (g)
T_1	1.0 IW/CPE + Black Polythene mulch	2.57 ^{bc}
T_2	1.0 IW/CPE + Silver Black Polythene mulch	2.69 ^{a}
T_3	1.0 IW/CPE + Organic mulch	2.35 ^{cde}
T_4	1.0 IW/CPE + without mulch	2.26 ^{efg}
T_5	0.8 IW/CPE + Black Polythene mulch	2.47^{bcd}
T_6	0.8 IW/CPE + Silver Black Polythene mulch	2.49 ^{ab}
T_7	0.8 IW/CPE + Organic mulch	2.33^{cdef}
T_8	0.8 IW/CPE + without mulch	2.19 ^{efgh}
T_9	0.6 IW/CPE + Black Polythene mulch	2.22 ^{efgh}
T_{10}	0.6 IW/CPE + Silver Black Polythene mulch	2.32 ^{def}
T_{11}	0.6 IW/CPE + Organic mulch	2.17^{fgh}
T_{12}	0.6 IW/CPE + without mulch	1.96 ^{jk}
T_{13}	0.4 IW/CPE + Black Polythene mulch	2.07^{hij}
T_{14}	0.4 IW/CPE + Silver Black Polythene mulch	2.15 ^{ghi}
T_{15}	0.4 IW/CPE + Organic mulch	1.99^{ijk}
T_{16}	0.4 IW/CPE + without mulch	1.89 ^{k}
S.Em±		0.06
C.D. (at 5%)		0.17
CV		4.42

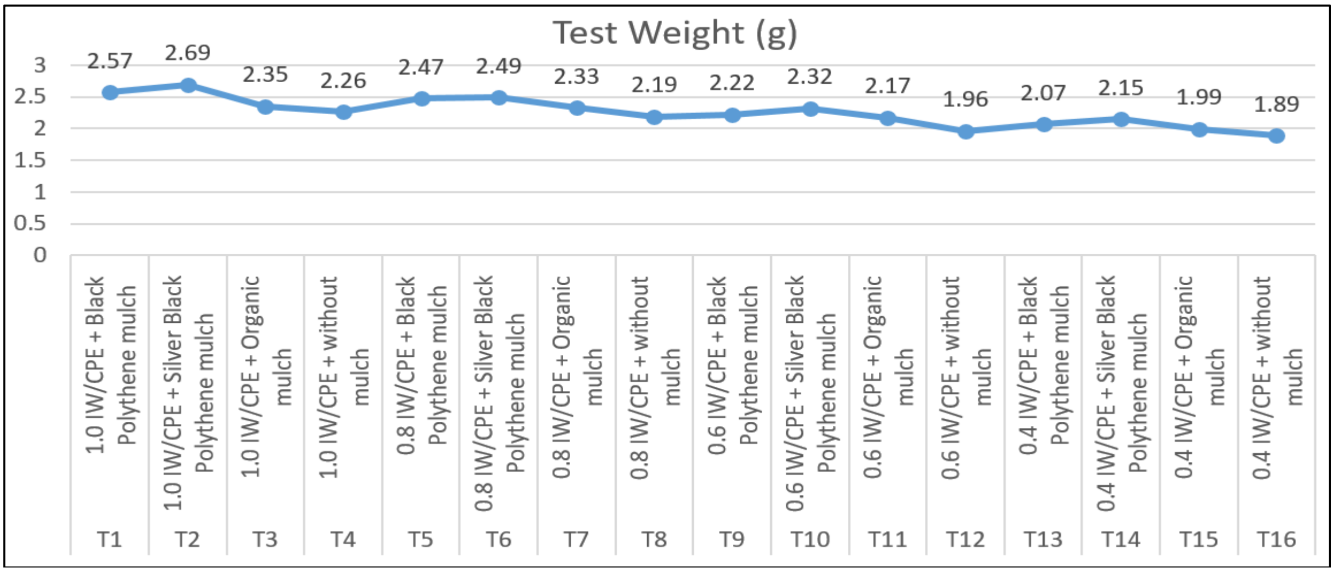

Fig 2: Effect of irrigation levels and mulching practices on Test weight (g) of Nigella Seeds.

4. Conclusion

The present study clearly demonstrates that irrigation scheduling and mulching practices exert a profound influence on the quality attributes of *Nigella sativa*. Moderate deficit irrigation at 0.4 IW/CPE significantly enhanced essential oil content and fat percentage, particularly when combined with organic or black polythene mulch, indicating that mild water stress creates favorable conditions for secondary metabolite synthesis and lipid accumulation. In contrast, higher irrigation levels (1.0 and 0.8 IW/CPE) in association with silver-black mulch reduced oil and fat content but improved test weight, suggesting a trade-off between biochemical enrichment and seed boldness. Severe water deficit without mulch, however, proved detrimental to physical seed quality by reducing test weight. Overall, the findings highlight that regulated deficit irrigation coupled with suitable mulching can effectively balance the physiological and biochemical processes in Nigella, ensuring enhanced seed quality and commercial value.

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