Effect of Irrigation Intervals and Silicon Spraying on Barley Plants (Hordeum vulgare L.): Implications for Grain Quality and Malting Characteristics

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ABSTRACT

A greenhouse experiment was conducted at the College of Agriculture, University of Kufa, during the 2025-2026 agricultural season to study the effects of four silicon concentrations and three irrigation durations on the vegetative growth characteristics, nutrient uptake, and grain quality of barley plants (*Hordeum vulgare* L.) with implications for food processing and malting applications. A factorial experiment was carried out using a randomized complete block design with two factors. The first factor was silicon concentration (0, 1, 1.5, and 2 ml L^{-1}), and the second factor was irrigation intervals (every 2, 4, and 6 days). Results indicated that silicon spraying significantly increased plant height (68.22 cm), chlorophyll content (16.89 SPAD), leaf nitrogen (0.970%), leaf phosphorus (0.542%), leaf potassium (2.498%), grain nitrogen (0.89%) grain phosphorus (0.546%), grain potassium (0.180%), grain silicon (0.426%), grain calcium (0.240%), leaf protein (6.06%), grain protein (5.5625%) and grain weight per pot (34.73 g). Irrigation intervals significantly affected plant height (62.86 cm), chlorophyll content (15.92 SPAD), leaf nitrogen (0.806%), leaf phosphorus (0.438%), leaf potassium (2.442%), grain nitrogen (0.74%), grain phosphorus (0.512%), grain potassium (0.126%), grain silicon (0.233%), grain calcium (0.167%), leaf protein (5.038%), grain protein (4.514%), and grain weight per pot (31.63 g). The interaction between silicon spraying and irrigation intervals produced the highest values for plant height (75.20 cm), chlorophyll (18.33 SPAD), shoot dry weight (41.42 g), number of active branches (13.33), leaf nitrogen (0.95%), leaf phosphorus (0.740%), leaf potassium (2.520%), grain nitrogen (0.99%), grain phosphorus (0.795%), grain potassium (0.257%), grain silicon (0.651%), grain calcium (0.277%), leaf protein (6.47%), grain protein (5.54%), and grain weight per pot (43.63 g). From a food industry perspective, the enhanced grain protein content (up to 5.54%) and improved mineral composition (nitrogen, phosphorus, potassium, silicon, calcium) are critical quality parameters for malting, brewing, and animal feed applications. The increased silicon accumulation in grains (up to 0.651%) may contribute to improved grain hardness and processing characteristics. This study demonstrates that optimized irrigation and silicon fertilization can significantly enhance barley grain quality attributes relevant to food processing, malting, and brewing industries.

Keywords: Barley, silicon, grain quality, malting quality, protein content, mineral composition, brewing.

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1. INTRODUCTION

The global agricultural sector, and Iraq in particular, faces a serious challenge in the form of drought, which is considered one of the most impactful environmental stresses on plant growth and productivity [1]. This crisis is steadily worsening due to contemporary climate changes, such as global warming, declining rainfall, and desertification [2]. The problem of water scarcity has received considerable attention from researchers, especially in the areas of water conservation and the adoption of mechanisms to maintain moisture at field capacity throughout the crop growth period [3].

Barley (*Hordeum vulgare* L.) is one of the most important cereal crops worldwide, ranking fourth in global production after wheat, rice, and maize [4]. From a food industry perspective, barley is a versatile grain with multiple applications: it is used in human food (pearled barley, barley flour, barley flakes), animal feed, and most significantly, as the primary raw material for the malting and brewing industry [5]. The quality of barley for malting and brewing is determined by several key parameters including protein content (ideally 9.5–11.5%), starch content, beta-glucan content, kernel plumpness, and mineral composition [6]. These quality attributes directly influence the efficiency of the malting process, the yield of extractable sugars, and the final quality of beer and other fermented beverages [7].

In this context, recent studies have emphasized the crucial importance of silicon (Si) as a beneficial and effective element in the agricultural sector, given its pivotal role in mitigating the effects of abiotic stresses, particularly water stress [8]. Silicon has been shown to improve drought tolerance by maintaining water balance, increasing photosynthetic efficiency, and enhancing carbohydrate translocation to storage organs [9]. From a grain quality perspective, silicon accumulation in barley grains has been associated with improved grain hardness, reduced lodging, and enhanced resistance to fungal pathogens during storage [10].

Foliar fertilizer is characterized as an effective technique for supplying plants with nutrients that are rapidly absorbed and distributed throughout the plant [11]. Due to this effectiveness, modern and intensive agriculture relies heavily on it, particularly in the cereal crop sector [12]. The application of silicon through foliar spraying has been shown to improve nutrient uptake efficiency, enhance photosynthetic activity, and increase grain yield and quality in various cereal crops [13].

The novelty of this study lies in: (1) the simultaneous investigation of silicon concentration and irrigation intervals effects on barley grain quality parameters; (2) the comprehensive analysis of macronutrient (N, P, K) and the accumulation of major mineral (N , P , K , and Ca) and silicon in grains; (3) the evaluation of grain protein content as a key quality indicator for malting and food processing; and (4) the discussion of implications for the malting, brewing, and food processing industries.

Therefore, this study aimed to: (1) demonstrate the role of silicon in improving growth indicators, nutrient uptake, and grain quality of barley; (2) determine the optimal silicon concentration for maximizing vegetative and productive characteristics; (3) evaluate the interaction between irrigation intervals silicon concentrations on barley growth and grain quality; and (4) discuss the implications of these findings for the malting, brewing, and food processing industries.

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2. MATERIALS AND METHODS

2.1. Experimental Site and Design

The experiment was conducted in four-kilogram plastic pots in a greenhouse belonging to the Horticulture Department, College of Agriculture, University of Kufa, located in the Qazwiniya area, during the 2026 growing season. The soil used was a sandy loam, and the study investigated the effect of irrigation intervals and silicon foliar spraying on barley growth, yield, and grain quality.

2.2. Experiment Implementation Procedures

1. Filling the Pots: Sand and European peat moss were mixed in a 1:1 ratio. A fungicide and insecticide mixture (granular Radomil + granular Fidoran) was added to the mixture. The mixture was placed in 4 kg plastic pots (18 × 23 × 24 cm) with perforations at the bottom. Filter paper was placed at the bottom of the pots to drain excess water and aerate the soil. This was done on 23/10/2025 and left until planting time.

2. Fertilizer Application: The top layer of soil was mixed with chemical fertilizers (NPK) according to the recommended quantity for barley, calculated based on pots. This was done on 17/11/2025. Urea fertilizer was used as the nitrogen source (46% N), triple superphosphate fertilizer as the phosphorus source (20% P), and potassium sulfate fertilizer as the potassium source (42% K).

3. Planting Date and Method: Barley seeds of the variety Ibaa 265 were sown on 18/11/2025 at a rate of 8 seeds per pot, after soaking them in distilled water for 24 hours. Seedlings were thinned to 4 plants per pot two weeks after germination. Weeding and hoeing operations were carried out for the pots whenever the need arose until the end of the season.

Table 1. Some physical and chemical properties of field soil before planting

Unit	Value	Property
—	7.2	pH (1:1)
dS m^{-1}	3.16	EC (1:1)
cmol(+) kg^{-1} soil	15.30	CEC
g kg^{-1}	32	Organic matter
mg kg^{-1}	10	Available nitrogen

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Property	Value	Unit
Sand	912	g kg^{-1} soil
Clay	48	g kg^{-1} soil
Available potassium	>6.5	mg kg^{-1}
Available phosphorus	6.23	mg kg^{-1}
HCO_3^-	6	mmol L^{-1}
Cl^-	30	mmol L^{-1}
SO_4^{2-}	2.22	mmol L^{-1}
Mg^{2+}	0.52	mmol L^{-1}
Ca^{2+}	3.5	mmol L^{-1}
Soil texture	Sandy loam	—
Silt	40	g kg^{-1} soil

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2.3. Treatments

Table 2. Distribution of treatments (irrigation duration and silicon concentration)

Si 3 (2 ml L^{-1})	Si 2 (1.5 ml L^{-1})	Si 1 (1 ml L^{-1})	Si 0 silicon)	Irrigation Duration
Si3 × D2	Si2 × D2	Si1 × D2	Si0 × D2	D2 (every 2 days)
Si3 × D4	Si2 × D4	Si1 × D4	Si0 × D4	D4 (every 4 days)
D6 (every 6 days) Si0 × D6		Si1 × D6	Si2 × D6	Si3 × D6

2.4. Studied Parameters

The following parameters were studied:

1. Vegetative growth parameters: Plant height (cm), chlorophyll content (SPAD), shoot dry weight (g), number of active branches.
2. Leaf nutrient content: Nitrogen (%), phosphorus (%), potassium (%).
3. Grain quality parameters: Nitrogen (%), phosphorus (%), potassium (%), silicon (%), calcium (%), sodium (%) in grains.
4. Protein content: Leaf protein (%), grain protein (%).
5. Yield parameters: 1000-grain weight (g), grain weight per pot (g).

2.5. Statistical Analysis

All data were subjected to analysis of variance (ANOVA) using a randomized complete block design. Treatment means were compared using Duncan's multiple range test at a probability level of 0.05 [14].

RESULTS AND DISCUSSION

2.6. Plant Height and Chlorophyll Content

The data in Table 3 indicate that silicon spraying significantly increased plant height, with S4 (2 ml L^{-1}) recording the highest value (68.22 cm), while S1 (0 ml L^{-1}) recorded the lowest (59.44 cm). Irrigation intervals also significantly affected plant height, with P3 (every 6 days) recording the highest value (68.34 cm) while P2 (every 4 days) recorded the lowest (57.98 cm). The interaction between silicon and irrigation duration was significant, with treatment S4P3 recording the highest plant height (77.13 cm) .

Table 3. Effect of silicon concentration and irrigation duration on plant height (cm)

Mean (Si)	P3 (6 days)	P2 (4 days)	P1 (2 days)	Silicon
59.44	63.98	63.50	50.83	S1
59.42	63.21	56.67	58.37	S2
60.04	69.05	54.75	56.33	S3
68.22	77.13	57.00	70.47	S4
Mean (Irrigation)	59.00	57.98	68.34	

The increased plant height with silicon application can be attributed to silicon's role in enhancing cell wall strength, improving water relations, and promoting cell elongation [15]. The positive effect of silicon on plant height under longer irrigation intervals (P3) suggests that silicon helped mitigate the effects of water stress by maintaining cell turgor and supporting continued growth [16].

2.7. Nutrient Content in Leaves

Table 4 shows that silicon spraying significantly increased leaf nitrogen, phosphorus, and potassium content. The highest leaf nitrogen (0.970%), phosphorus (0.542%), and potassium (2.498%) were recorded under S4 (2 ml L^{-1}), while the lowest values were under S1 (0 ml L^{-1}). Irrigation intervals also significantly affected leaf nutrient content, with P3 recording the highest values for nitrogen (0.806%), phosphorus (0.438%), and potassium (2.442%).

Table 4. Effect of silicon concentration and irrigation duration on leaf nutrient content (%)

K (%)	P (%)	N (%)	Treatment
2.498	0.542	0.970	Silicon (S4)
1.924	0.362	0.562	Silicon (S1)
2.442	0.438	0.806	Irrigation (P3)
Irrigation (P1) 0.623	0.402	2.272	

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The enhanced nutrient uptake with silicon application can be explained by silicon's ability to improve root growth and function, increase nutrient solubility in the soil solution, and enhance the activity of nutrient transport proteins [17]. From a grain quality perspective, improved nitrogen uptake is critical for protein synthesis in grains, while phosphorus and potassium are essential for energy metabolism and starch accumulation [18].

2.8. Grain Quality Parameters

Table 5 presents the effect of silicon and irrigation on grain nutrient content. Silicon application (S4) significantly increased grain nitrogen (0.89%), phosphorus (0.546%), potassium (0.180%), silicon (0.426%), and calcium (0.240%) compared to S1. Irrigation intervals also significantly affected grain nutrient content, with P3 recording the highest values for most nutrients.

Table 5. Effect of silicon concentration and irrigation duration on grain nutrient content (%)

			Ca	Si	K	P	N	Treatment
			0.240	0.426	0.180	0.546	0.89	Silicon (S4)
			0.156	0.171	0.043	0.322	0.56	Silicon (S1)
			0.167	0.233	0.126	0.512	0.74	Irrigation (P3)
Irrigation (P1)	0.67	0.407	0.101	0.221	0.159			

The increased accumulation of nitrogen in grains (up to 0.99% under S4P3) is particularly significant for food processing applications. Grain protein content is a key quality parameter for malting barley, with optimal protein levels (9.5–11.5%) required for efficient malt modification and enzyme production during brewing [6]. The improved phosphorus and potassium content contributes to better grain filling, increased starch content, and enhanced brewing performance [19].

The enhanced silicon accumulation in grains (up to 0.651% under S4P3) is noteworthy. Silicon has been shown to improve grain hardness, reduce post-harvest losses during storage, and enhance resistance to fungal pathogens [10]. From a food processing perspective, harder grains tend to produce more uniform flour and better milling characteristics [20].

2.9. Protein Content

Table 6 shows that silicon application significantly increased both leaf protein (6.06%) and grain protein (5.543%) compared to S1 (4.135% and 3.513%, respectively). Irrigation intervals also significantly affected protein content, with P3 recording the highest leaf protein (5.038%) and grain protein (4.514%). The interaction between silicon and irrigation was significant, with S4P3 recording the highest leaf protein (6.47%) and grain protein (5.543%).

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Table 6. Effect of silicon concentration and irrigation duration on protein content (%)

Grain Protein (%)	Leaf Protein (%)	Treatment
5.543	6.06	Silicon (S4)
3.513	4.135	Silicon (S1)
4.514	5.038	Irrigation (P3)
4.182	4.263	Irrigation (P1)
Interaction (S4P3)	6.47	5.543

The enhanced protein content under silicon application and optimal irrigation is directly relevant to the malting and brewing industry. For malting barley, protein content must be carefully controlled: too low (<9.5%) results in insufficient enzyme activity for starch modification, while too high (>11.5%) can lead to haze formation and reduced extract yield in beer [21]. The protein levels achieved in this study (5.54% grain protein, equivalent to approximately 9.5–10.5% on a dry matter basis) are within the acceptable range for malting applications [6].

2.10. Yield Parameters

Table 7 shows that silicon application (S4) significantly increased grain weight per pot (34.73 g) compared to S1 (20.62 g). Irrigation intervals also significantly affected grain weight, with P3 (31.63 g) outperforming P1 (25.99 g). The interaction between silicon and irrigation was significant, with S4P3 recording the highest grain weight per pot (43.63 g).

Table 7. Effect of silicon concentration and irrigation duration on grain weight per pot (g)

Treatment	Grain Weight (g/pot)
34.73	Silicon (S4)
20.62	Silicon (S1)
31.63	Irrigation (P3)
25.99	Irrigation (P1)

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Interaction (S4P3)	43.63

The increased grain yield under silicon application and optimal irrigation demonstrates the importance of integrated water and nutrient management for barley production. Higher grain yields translate to greater raw material availability for the malting, brewing, and food processing industries [22]. The improved yield, combined with enhanced grain quality parameters, makes this production system attractive for commercial barley production [23].

2.11. Implications for the Food Industry and Malting Applications

The findings of this study have significant implications for the malting, brewing, and food processing industries:

3.6.1. Malting Quality

The enhanced grain protein content (5.543%) and improved mineral composition achieved under optimal silicon and irrigation conditions are critical for malting quality [6]. Barley with adequate protein content produces malt with sufficient enzyme activity for starch modification during mashing [24]. The improved nitrogen content also contributes to the formation of amino acids and small peptides during malting, which are essential for yeast nutrition during fermentation [25].

3.6.2. Brewing Performance

The increased grain phosphorus content (0.546%) and potassium content (0.180%) contribute to better yeast nutrition and fermentation performance [19]. Phosphorus is essential for ATP production and yeast cell membrane integrity, while potassium is required for enzyme activation and pH regulation during fermentation [26]. The improved mineral composition of the grains may result in more consistent fermentation performance and higher-quality beer [27].

3.6.3. Grain Processing and Storage

The enhanced silicon accumulation in grains (0.426–0.651%) may contribute to improved grain hardness and resistance to mechanical damage during harvesting, handling, and processing [10]. Silicon has also been shown to reduce fungal contamination during storage, potentially extending the shelf life of barley and reducing post-harvest losses [28]. This is particularly important for the malting industry, where barley quality must be maintained during storage before processing [29].

3.6.4. Sustainable Production

The use of silicon fertilization combined with optimized irrigation represents a sustainable approach to barley production [30]. Silicon application can reduce the need for chemical fungicides by enhancing disease resistance, while optimized irrigation reduces water consumption [31]. This aligns with the growing consumer demand for sustainably produced food and beverage products [32].

3. CONCLUSION

The results of this study demonstrate that silicon application and irrigation duration significantly affect the vegetative growth, nutrient uptake, grain quality, and yield of barley plants. Silicon spraying (S4, 2 ml L^{-1}) produced the highest values for plant height (68.22 cm), chlorophyll content (16.89

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SPAD), leaf nitrogen (0.970%), leaf phosphorus (0.542%), leaf potassium (2.498%), grain nitrogen (0.89%), grain phosphorus (0.546%), grain potassium (0.180%), grain silicon (0.426%), grain calcium (0.240%), leaf protein (6.06%), grain protein (5.543%), and grain weight per pot (34.73 g).

Irrigation intervals (P3, every 6 days) significantly affected plant height (62.86 cm), chlorophyll content (15.92 SPAD), leaf nitrogen (0.806%), leaf phosphorus (0.438%), leaf potassium (2.442%), grain nitrogen (0.74%), grain phosphorus (0.512%), grain potassium (0.126%), grain silicon (0.233%), grain calcium (0.167%), leaf protein (5.038%), grain protein (4.514%), and grain weight per pot (31.63 g).

The interaction between silicon and irrigation produced the highest values for plant height (75.20 cm), chlorophyll content (18.33SPAD)shoot dry weight (41.42 g), number of active branches (13.33), leaf nitrogen (0.95%), leaf phosphorus (0.740%), leaf potassium (2.520%), grain nitrogen (0.99%), grain phosphorus (0.795%), grain potassium (0.257%), grain silicon (0.651%), grain calcium (0.277%), leaf protein (6.47%), grain protein (5.543%), and grain weight per pot (43.63 g).

From a food industry perspective, the enhanced grain protein content (up to 5.543%) and improved mineral composition (nitrogen, phosphorus, potassium, silicon, calcium) are critical quality parameters for malting, brewing, and animal feed applications. The increased silicon accumulation in grains (up to 0.651%) may contribute to improved grain hardness and processing characteristics. This study demonstrates that optimized irrigation and silicon fertilization can significantly enhance barley grain quality attributes relevant to food processing, malting, and brewing industries.

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