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Effects of Various Irrigation Water Sources on the Growth of Mustard Green (*Brassica chinensis* var. *parachinensis*)

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ABSTRACT

Mustard green (Brassica chinensis var. parachinensis) was the main crop produced after tomato in 2020, with water being a critical factor driving its production volume. Over the last two years, Malaysia has encountered prominent water crises, specifically water supply disruptions and water pollution, which have compromised water sources in terms of both quantity and quality. This study was conducted to evaluate the effects of different irrigation water types on plant performance and to identify the optimal water source for maximizing plant growth and development. The experiment was established at Selayang Baru, Selangor, using a Randomized Complete Block Design (RCBD) featuring 4 treatments and 3 replications. The irrigation treatments evaluated were: tap water (T1), rainwater (T2), a combination of tap water and rainwater (T3), and distilled water (T4). Core growth parameters measured included plant height, number of leaves, leaf surface area, collar diameter, and fresh weight. Data collection was carried out weekly from week 2 post-sowing until the final harvest in week 6. Collected data were subjected to Analysis of Variance (ANOVA), and treatment means were separated using the Least Significant Difference (LSD; P < 0.05) test. The findings revealed no significant differences among the four water types or blocks regarding general plant performance. Readily available water sources demonstrated growth impacts comparable to scarce or highly processed water alternatives. These results indicate that cost-effective tap water can be successfully used without diminishing crop performance, eliminating the need for expensive or hard-to-source water types. Nonetheless, crops irrigated with rainwater achieved a higher mean growth performance, proving safe for irrigation due to acceptable baseline pH and Total Dissolved Solids (TDS) levels. This offers critical economic and ecological insights for gardeners and farmers aiming to implement rainwater harvesting to minimize utility expenses and conserve municipal water resources.

1. Introduction

Vegetables constitute an indispensable component of the daily human diet. Consequently, market demand remains consistently robust and continuously escalating. Supported by the National Agro-Food Policy 2011–2020, national vegetable production in Malaysia surged from 1.6 million

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metric tonnes in 2010 to 2.4 million metric tonnes in 2020, reflecting a steady annual growth rate of 4.5%. Notably, mustard green stands as the primary crop produced nationally after tomato as of 2020 (Crop Statitstics 2020). To fulfill this non-stop market demand, consistent supply streams are mandatory. Faced with this massive demand surge, commercial farmers across regional hubs such as Johor Bahru, Bentong, and Kinta continuously maximize seasonal outputs to sustain market equilibria.

This agricultural sector demands substantial financial investments. According to national crop statistics, the production costs for cultivating mustard green are high, averaging approximately RM 12,578 per production cycle to cover development costs, physical inputs, and manual labor. Material input costs encompass vital assets including high-quality seeds, growing media, fertilizers, and pest management regimes.

Beyond these inputs, water remains one of the most critical biological determinants governing overall crop health and vegetative yield. Cultivated crops require adequate hydration to secure premium commercial yields, with agricultural operations commanding roughly 70% of total national water withdrawals (Mancouso *et al.*, 2015). Concurrently, domestic water requirements continue to expand alongside population growth, with Malaysia's population projected to scale by an additional 12.9 million individuals over a cumulative 30-year horizon. Therefore, water sources must remain highly reliable, continuously available, and secure against contamination.

However, over the past two years, Malaysia has faced recurring water crises that threaten the stability of water reserves in both volume and purity: specifically acute water supply disruptions and river pollution (Mohd Firdaus Abdullah *et al.*, 2019). In response to these vulnerabilities, utilizing harvested rainwater emerges as a viable alternative strategy to decrease reliance on municipal tap water and lower overhead utility costs for farmers. Conversely, producing alternative pure sources like distilled water demands specialized, high-energy machinery, though distilled water provides unique physiological benefits, such as accelerating seed germination rates [14].

2. Literature Review

Mustard green, locally designated as *sawi hijau*, represents one of the primary leafy green vegetables cultivated extensively throughout Asian territories, particularly within Malaysia (Kamaruddin *et al.*, 2014). This leafy commodity is also commonly referred to as Chinese flowering cabbage, deriving from its Mandarin name *"caixin"*, which translates to "the heart of the cabbage". Mustard green features an accelerated vegetative lifecycle, reaching commercial harvest maturity within 30 to 35 days, and offers a rich nutritional profile packed with essential vitamins and dietary fiber.

Biochemically, approximately 90% of the raw plant matrix comprises water. Every 100 g portion of edible tissue delivers approximately 30.0 kcal of metabolic energy, 2.0 g of crude protein, 4.0 g of carbohydrates, 140.0 mg of calcium, 80.0 mg of phosphorus, 1.3 mg of iron, and 0.8 g of dietary fiber. Furthermore, it supplies key micronutrients, including 0.09 mg of Vitamin B1 (Thiamine), 0.27 mg of Vitamin B2 (Riboflavin), and 90.0 mg of Vitamin C (ascorbic acid) (Kamaruddin *et al.*, 2014). Research confirms that mustard greens contain dense concentrations of organosulfur compounds, which have been clinically shown to mitigate risks associated with cardiovascular disease and specific cancers. Additionally, its ascorbic acid content serves as a robust systemic antioxidant, facilitating vital collagen synthesis and strengthening immune functions (Wachtel-Galor *et al.*, 2008)

In this study, various sources of water will be used to irrigate the sample plant. Tap water is the most common and accessible water source, supplied directly via municipal distribution networks. This water undergoes rigorous chemical processing at centralized treatment facilities to satisfy safety standards before consumer delivery. Public declarations from the Ministry of Water, Land, and Natural Resources during parliamentary sessions have affirmed that Malaysia's domestic tap water infrastructure supplies safe, acceptable water that poses no acute health hazards or physical discomfort to the population. With the national population exceeding 32 million, coupled with rapid industrialization and agricultural expansion, domestic water demand has tripled over recent decades (Che-Ani *et al*., 2009). Structural stress occurs when supply reserves fail to meet consumer volumes or when raw resources face pollution. For example, communities across Selangor and Kuala Lumpur frequently deal with municipal water disruptions. Many underground distribution lines have remained unreplaced past their service lifespans, leading to line ruptures and severe infrastructure failures, which directly cause local water scarcity [2].

Beyond infrastructure failures, unlawful dumping of toxic chemical effluents into river basins introduces major ecological and human health risks. In the meantime, rainwater represents a naturally clean, unpolluted, and completely cost-free water resource. Precipitation acts as a pristine water asset; as atmospheric moisture condenses and falls, the resulting water is valued for its low mineral hardness and purity. This process is a core element of the global hydrological cycle, which drives the continuous moisture exchange between the earth's oceans and the atmosphere. Standard weather patterns including rain, hail, sleet, and snow drive this natural cycle. Nevertheless, falling precipitation, including localized mist and fog, can absorb trace concentrations of airborne dust, gases, and particulate matter [1]. As drops descend through the atmosphere, they dissolve carbon dioxide and nitrogen, becoming slightly acidic. Although the atmosphere is composed of 78% elemental nitrogen, plants cannot assimilate it directly due to the high metabolic energy required to break its molecular bonds [18]. However, falling rain captures these micronutrients and brings them down into the soil solution, where they can be quickly absorbed by root systems to accelerate plant growth [9].

Meanwhile, distilled water is produced through thermal distillation, a process that boils raw water to separate pure H_2O from non-volatile contaminants. These contaminants include heavy metals and inorganic minerals with high boiling points. While volatile organic compounds like pesticides and herbicides may possess boiling points below that of water, thermal management ensures that pure steam is isolated, captured, and re-condensed into liquid form. Before final collection in storage tanks, the water passes through secondary activated carbon filtration systems to eliminate any remaining trace impurities. This intensive treatment effectively eliminates almost all foreign elements, including sodium, calcium, magnesium, iron, manganese, fluorides, and nitrates. Because it is nearly free of dissolved salts and minerals, distilled water is readily absorbed by seed coats, which can help accelerate early germination [14].

Monitoring irrigation water pH is vital for food safety and tracking resource quality. This parameter is a key factor in crop development because it alters chemical reactions and nutrient availability within both the water and the soil matrix. The exact mechanisms by which root systems assimilate essential nutrients are strongly influenced by baseline pH readings. For the majority of commercial fruit and vegetable crops, the optimal irrigation pH range lies between 6.0 and 7.0, which allows for maximum nutrient uptake. If the solution shifts too far toward acidic or alkaline extremes, crops quickly develop macro and micronutrient deficiencies [3,9]. In addition, electrical conductivity (EC) is the numerical measurement of an aqueous solution's capacity to carry an electrical current. In open agricultural catchments, EC monitoring can track runoff events that introduce harmful pathogens into irrigation supplies. Furthermore, EC serves as a reliable proxy for salinity, measuring the total concentration of dissolved salts referred to as Total Dissolved Solids (TDS) [7]. As the volume of dissolved salts rises, the solution's conductivity increases proportionally, because these compounds dissociate into positively and negatively charged ions that conduct current. High baseline salinity can trigger nutrient toxicity and restrict osmotic water uptake by root systems [9]. Elevated irrigation EC can also inhibit basic root absorption, stunting vegetative development [3].

3. Methodology

Water Sample Collection

Tap water and rainwater samples were collected directly. Rainwater was harvested from rooftop catchments into polyethylene storage tanks before being transferred into 25 L plastic polyethylene containers. Distilled was collected and stored in a 160 L drum. All water treatments were allowed to settle before use to facilitate baseline sedimentation.

Water Quality Analysis

Before irrigation, all water treatments were tested using standardized pH and TDS meters. This allowed for the evaluation of pH, electrical conductivity (EC), and total dissolved solids (TDS) to identify any distinct chemical advantages among the water types.

Experimental Design and Block Setup

The fieldwork used a Randomized Complete Block Design (RCBD) featuring three replications for each treatment. Seedlings were grouped into blocks based on phenotypic uniformity, ensuring every block contained all four treatments. Each treatment within a block contained 3 individual crop samples. Experimental polybags were labelled by block, treatment number, and replication, and then arranged vertically.

Germination and Transplanting Regimes

Seeds were soaked overnight in their respective water treatments to accelerate germination. Afterward, the seeds were placed into germination trays and kept under a protective rain shelter. This shelter prevented exposure to ambient rainfall, ensuring precise control over irrigation volumes and water types. Trays were organized by treatment, and the total number of sprouted seeds was recorded daily to assess germination velocity. Irrigation was applied twice daily at 09:00 am and 05:00 pm. At the end of the germination phase, final success rates were calculated.

Growing Media Preparation

The growing medium consisted of a blend of two commercial soils: "6-in-1 Special Soil" sourced from a nursery in Gombak, Selangor and "Baba Vegetable Soil" purchased online. The 6-in-1 organic medium contained a mixture of cocopeat, burnt soil, river sand, rice hulls, organic fertilizer, and black soil. The Baba vegetable soil consisted of peat moss, organic compost, and a clay-breaking agent.
To prepare the 36 experimental units, 4 packs of 28 L Baba soil were thoroughly blended with 6 packs of 20 L 6-in-1 soil. The uniform media mixture was then filled into 12" $\times$ 12" polybags. Healthy, uniform seedlings were transplanted into the polybags 10 to 14 days after sowing, or once they had developed 3 to 4 true leaves.

Agronomic Maintenance

Crops received 2 teaspoons of specialized fertilizer per plant every week, alternating between Baba Leafy Fertilizer and Milagro Organic Fertilizer. Daily irrigation was applied using 150 mL of the designated water type per polybag during each watering session. Yellow sticky traps and organic biopesticides were used to manage insect pests. Pest control applications were carried out weekly during the late evening post-irrigation.

Vegetative Growth Measurements

Growth parameters were measured and recorded weekly. At the end of the 7-week cultivation cycle, the crops were harvested, and the shoot systems were separated from the roots. Root structures were washed thoroughly, and the fresh weights of both shoots and roots were recorded using a digital scale.

Statistical Analysis

Data compilation and primary processing were completed using Microsoft Excel, followed by Analysis of Variance (ANOVA) procedures. Treatment means were separated using the Least Significant Difference (LSD) test at a significance threshold of P = 0.05.

4. Results and Discussion

Baseline Irrigation Water Quality Metrics

Chemical analysis showed distinct differences in water quality parameters among the four treatments (Table 1).

Table 1
Water quality test on different types of water irrigation

Test	Tap water	Rainwater	Combination tap water and rainwater	Distilled water
pH	6.55 - 7.56	5.65 - 6.28	6.23 - 7.06	5.5 – 6.5
Total Dissolve Solid (µs/cm)	34 - 84	16 – 50	25 – 58	0
EC (ppm)	68 – 168	32 – 101	50 – 116	0

Note: Data values represent measured ranges throughout the experiment.

Rainwater pH ranged from 5.65 to 6.28, indicating mild acidity. In contrast, tap water and the combined water option maintained nearly neutral pH ranges of 6.55 to 7.56 and 6.23 to 7.06, respectively. Distilled water registered between 5.50 and 6.50, remaining mildly acidic to neutral. Managing water pH is essential because it directly influences soil solution chemistry, nutrient solubility, and root absorption efficiency.

The ideal irrigation pH for most vegetable crops ranges from 5.5 to 6.5, which optimizes nutrient availability. Highly acidic or alkaline shifts can restrict essential macronutrients (nitrogen, phosphorus, potassium, sulfur, calcium, magnesium) and micronutrients (iron, boron, copper, zinc), leading to deficiencies. Furthermore, an irrigation pH above 8.0 can cause calcium precipitation, which can clog spray nozzles and emitters. Conversely, a pH below 6.0 can cause corrosion in metal pipes and irrigation fittings [3].

Rainwater TDS readings ranged from 16 to 50 µs/cm, whereas municipal tap water recorded higher levels between 34 and 84 µs/cm. The combined water treatment fell between these two, at 25 to 58 µs/cm, while distilled water recorded 0 µs/cm due to its lack of minerals and impurities. Given that the acceptable salinity threshold for vegetable irrigation is 0 to 500 µs/cm, all tested water sources fell safely within acceptable limits for crop cultivation [3].

Seed Germination Dynamics

Seed germination rates varied across the 14-day observation period based on the water type used (Table 2).

Table 2
Cumulative seed germination progress over 14 days

Day	Treatment (No. of seeds germinated)			
	1	2	3	4
1	0	0	0	0
2	0	0	0	0
3	16	21	16	14
4	22	23	24	20
5	23	23	24	20
6	23	23	24	22
7	23	23	24	22
8	23	23	24	22
9	24	24	24	22
10	24	24	24	22
11	24	24	23	22
12	24	24	23	22
13	24	24	23	22
14	24	24	22	22
Final seed germinated	24	24	22	22
Germination rate %	100	100	91.67	91.67

Note: Initial batch size was 24 seeds per treatment.

Both tap water and rainwater treatments achieved 100% total germination, while the combined and distilled water treatments reached 91.67%. These closely matched results indicate that all four water sources are suitable for initiating germination.

However, early growth rates varied on Day 3. Rainwater recorded the highest initial count with 21 sprouted seeds, followed by tap water and combined water with 16 seeds each, while distilled water was slower at 14 seeds. Rainwater's faster germination velocity may be linked to its low TDS profile, which can support rapid moisture imbibition through seed coats [14].

Analysis of Variance (ANOVA) on Phenotypic Parameters

ANOVA was used to assess the influence of the water treatments and experimental blocks on growth parameters (Table 3).

Table 3
ANOVA mean square values for mustard green growth parameters

Source of variation	df	Leaf surface area(cm²)	Height (cm)	Leaves number	Collar diameter (mm)	Fresh weight (g)
Treatment	3	14676.29^{ns}	11.06^{ns}	9.00^{ns}	6.01^{ns}	70.59^{ns}
Block	2	5591.78^{ns}	12.12^{ns}	3.25^{ns}	2.40^{ns}	24.75^{ns}
Error	6	11508.20	8.46	3.25	2.04	43.75

Note: **, significant at P ≤ 0.001; *, significant at P ≤ 0.05; ns, not significant

The results showed that different water treatments did not produce statistically significant variations (P ≤ 0.05) in leaf surface area, plant height, leaf number, collar diameter, or fresh weight. This indicates that all four water types led to comparable vegetative development. The uniform results suggest that using alternative water sources did not disrupt plant metabolism, as all treatments maintained acceptable pH, TDS, and EC ranges. Similarly, variations between blocks were not statistically significant, indicating uniform conditions across the experimental plots. This lack of block variance may be due to two factors: first, horizontal block alignment at the cultivation site may have introduced orientation errors, suggesting vertical block arrangements for future trials; second, variation within the blocks may have limited standard RCBD homogeneity.

Mean Separation Analysis of Growth Characteristics

Treatment and block means were evaluated using Least Significant Difference (LSD) testing (Table 4).

Table 4
Mean separation values for mustard green growth characteristics

Source of variation	Leaf surface area (cm²)	Height (cm)	Leaves number	Collar diameter (mm)	Fresh weight (g)
Treatment					
1	324.50^{a}	20.60^{a}	14.33^{a}	9.35^{ab}	18.87^{a}
2	475.97^{a}	21.50^{a}	13.33^{ab}	10.96^{a}	28.90^{a}
3	337.00^{a}	17.07^{a}	10.33^{b}	7.74^{b}	20.00^{a}
4	352.33^{a}	19.40^{a}	12.00^{ab}	8.30^{ab}	18.90^{a}
Block					
1	380.48^{a}	20.00^{a}	12.75^{a}	9.39^{a}	21.68^{a}
2	331.70^{a}	17.50^{a}	11.50^{a}	8.21^{a}	19.18^{a}
3	405.18^{a}	21.18^{a}	13.25^{a}	9.67^{a}	24.15^{a}

Note: Different letters indicate significant difference among treatment.Values are expressed as mean.

LSD testing confirmed that leaf surface area, plant height, total leaf number, and fresh weight did not differ significantly among the four water treatments. However, rainwater irrigated crops showed slightly higher mean growth values across several parameters, which may be due to the trace nutrients and suspended particles naturally found in rainwater [1]. Dissolved elements in rainwater are easily absorbed by plants, and previous studies have linked rainwater use to higher levels of nitrogen, potassium, phosphorus, and sodium within plant tissues.

For collar diameter, a significant difference was observed between the rainwater (T2) and combined water (T3) treatments, with rainwater producing the largest overall diameters. This improvement is likely related to rainwater's lower TDS profile (16–50 µs/cm). Low-salinity water helps dilute accumulated salts in the root zone, lowering osmotic stress and facilitating water uptake (Santini *et al*., 2014). This steady upward water movement can improve xylem water potential and support radial stem expansion [16].

Regarding leaf counts, tap water-irrigated plants averaged more leaves than those under the rainwater treatment. Leaf loss in some groups was influenced by environmental factors and localized pest pressure, as stable microclimates support uniform foliage development while poor physical conditions can slow growth. Sucking insect pests, primarily leaf miners and flies, damaged the leaves, causing curling, stiffness, and brittleness. This damage also weakened petioles, leading to premature leaf detachment and abscission.

5. Conclusion

In conclusion, the harvested rainwater, domestic tap water, and distilled water tested in this study met baseline safety thresholds for irrigation, as shown by their stable pH and TDS values. The results indicate that using rainwater or distilled water does not negatively impact crop health, as all parameters remained within acceptable limits. Rainwater produced slightly higher mean values for several growth characteristics, though the differences were not statistically significant. This supports the use of rainwater harvesting as a practical strategy for home gardeners and commercial farmers looking to reduce utility costs.

Nevertheless, domestic agriculture relies heavily on tap water due to its consistent availability across all seasons, whereas rainwater availability remains dependent on weather patterns. To balance resource availability and cost management, blending or alternating between tap water and rainwater offers a practical solution. This dual approach helps conserve natural resources while reducing monthly municipal water bills. Looking forward, expanding alternative water management options can provide both economic and environmental benefits for the agricultural sector. Developing dedicated rainwater harvesting systems would allow farmers to store surface runoff for dry periods. When rainwater is abundant, a mixing ratio of 2 parts rainwater to 1 part tap water is recommended to optimize water use efficiency.

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