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Effect of planting density on the growth and yield of *Brassica nipposinica* L. (Mizuna)

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Abstract
The study examines the effect of different planting densities on the growth and yield of *Brassica nipposinica* L. (Mizuna), an important leafy green in diverse culinary applications. Growth metrics such as plant height, leaf count, and biomass accumulation were monitored, alongside yield parameters including total fresh weight and leaf area index.
Findings revealed that planting density significantly influences growth patterns and yield outcomes. At low planting density, individual plants exhibited robust growth but the overall yield per unit area was suboptimal. Medium planting density emerged as the most efficient, balancing plant competition and resource availability to maximize yield per area. Conversely, high planting density led to excessive competition, stunting growth and diminishing yield per plant.
This study provides critical data to inform planting strategies for Mizuna and potentially other leafy greens, promoting enhanced agricultural productivity. Further investigation is suggested to assess the interplay between planting density and variables such as soil fertility and water management to refine cultivation practices.

Keywords: *Brassica nipposinica* l, mizuna, planting density, crop management, leafy vegetables, plant spacing

Introduction

Brassica nipposinica L., commonly known as Mizuna, is a leafy green vegetable valued for its mild flavor, high nutritional content, and versatility in culinary uses. Originating from Japan, Mizuna has gained popularity worldwide, particularly in salads and stir-fries, due to its tender leaves and rapid growth cycle. As consumer demand for healthy and diverse greens increases, optimizing the cultivation practices for Mizuna becomes crucial for achieving high productivity and sustainability.

Planting density is a critical agronomic factor that can significantly influence the growth and yield of crops. It affects various physiological and developmental processes, including light interception, nutrient uptake, and space utilization. In leafy vegetables like Mizuna, achieving the optimal planting density is essential to maximize yield without compromising the quality of the produce.

Previous studies on Brassica species have shown that both excessively high and low planting densities can adversely affect plant performance. High densities may lead to intense competition for light, water, and nutrients, resulting in stunted growth and lower individual plant yields. Conversely, low planting densities might not fully utilize the available growing space, leading to suboptimal total yield per unit area despite the larger size of individual plants. This study aims to investigate the effect of different planting densities on the growth and yield of *Brassica nipposinica* L. (Mizuna). By evaluating distinct planting densities we seek to determine the density that optimizes both individual plant growth and overall yield per area. The findings of this research are expected to provide valuable insights for growers and agricultural practitioners, enabling them to enhance the efficiency and sustainability of Mizuna cultivation. In the following sections, we present the materials and methods used for the experimental setup, the results obtained, and a discussion of the implications of these findings for Mizuna cultivation. Through this study, we hope to contribute to the broader understanding of planting density effects in leafy green vegetables and support the development of best practices for their cultivation.

Materials and Methods of Research

Materials

- ***Brassica nipposinica* L (TN23):** Strong growth, good disease resistance, and wide adaptability. The plant reaches an average height of 30–35 cm, with deeply lobed leaves. Purity (P) is ≥ 98%, germination rate (G) is ≥ 85%, and moisture content (H) is ≤ 8%.
- ***Brassica nipposinica* L (PN28):** The leaves have serrated edges and a light green color, with good disease resistance. The growth period ranges from 25 to 30 days. Purity (P) is ≥ 98%, germination rate (G) is ≥ 85%, and moisture content (H) is ≤ 10%.

Research Methods: The experiment involved two factors and was arranged in a completely randomized block (RCB) design with 8 treatments and 3 replications.

- **Factor A:** Variety.
- **A1:** TN23.
- **A2:** PN28.

Factor B: Planting density.

- **B1:** 108 plants/m² (spacing 10 × 10 cm).
- **B2:** 72 plants/m² (spacing 10 × 15 cm).
- **B3:** 48 plants/m² (spacing 15 × 15 cm).
- **B4:** 36 plants/m² (spacing 20 × 15 cm).

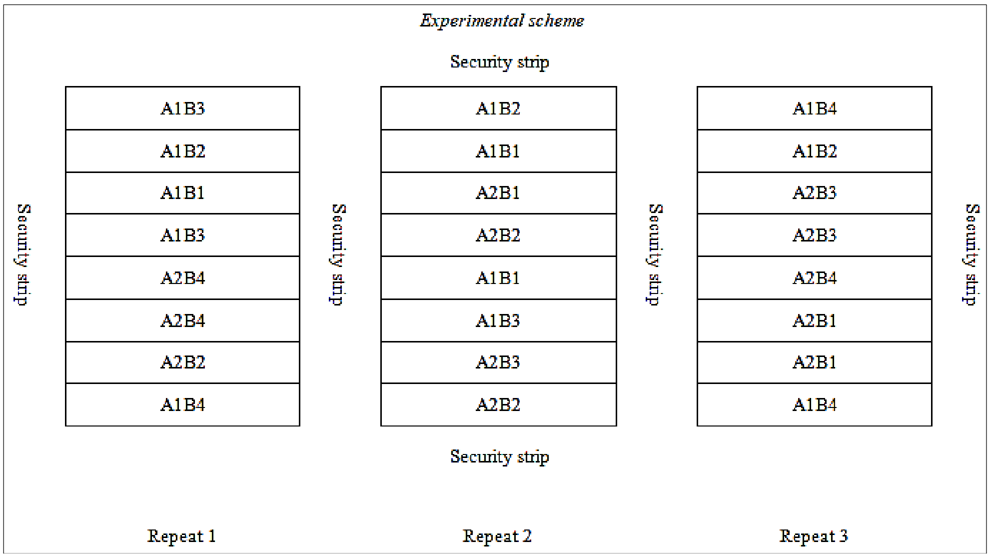

Fig 1: Experimental scheme

Research Results and Discussion

Table 1: The influence of planting density on the plant height of TN23 and PN28 *(Unit: cm)*

Variety (A)	Density (B)				Average (A)
	B1	B2	B3	B4	
A1	29,6 a	29,3 a	25,1 cd	25,1 cd	27,27 A
A2	26,1 cb	27,1 b	24,8 cd	23,8 d	25,45 B
Average (B)	27,85 A	28,20 A	24,95 B	24,45 B	
CV % = 3,7					

The data in Table 1 indicate that planting density has varying effects on the plant height of TN23 and PN28 at harvest time. The tallest plants of TN23 were observed at planting densities of 72 and 108 plants/m², while the shortest were recorded at 36 plants/m² for both TN23 and PN28. This difference is statistically significant at the 95% confidence level. The data also reveal that as planting density increases, the plant height of TN23 and PN28 tends to increase. However, the increase in plant height is not proportional to the increase in planting density. This suggests that at optimal planting densities, Mizuna varieties compete for light, resulting in upward growth to avoid shading each other. At sparse planting densities, plants receive sufficient light and space to develop leafy growth, hence resulting in shorter plant heights.

The data in Table 2 show that planting density and plant variety significantly affect leaf metrics of the two Mizuna varieties at harvest time, with statistically significant differences at the 95% confidence level.

High planting densities (72 and 108 plants/m²): The TN23 variety reaches maximum height, indicating plants must stretch upwards to compete for sunlight. This may be attributed to plants at higher densities needing to grow vertically to capture sufficient sunlight, thereby stimulating height growth.

Low planting density (36 plants/m²): Both TN23 and PN28 exhibit their shortest heights. At low planting densities, plants have ample light and space, leading to a focus on leaf development rather than height.

Although plant height increases with increasing planting density, the rate of increase is not proportional. This could be due to physiological limitations where at very high densities, plants cannot continue to increase in height due to resource limitations such as nutrients and water.

At high planting densities, plants compete intensely for light, promoting vertical growth. At low planting densities, plants have more space to develop leafy growth, reducing the need for height development.

Planting density affects leaf size and number, as plants allocate resources differently depending on space and light competition. Each plant variety exhibits distinct growth characteristics, hence differing responses to changes in planting density.

Table 2: Impact of planting density on leaf parameters of TN23 and PN28

Parameters	Variety (A)	Density (B)				Average (A)
		B1	B2	B3	B4	
Number of leaves per plant (leaves)	A1	8,30 bc	7,70 bc	8,00 bc	8,70 b	8,10 A
	A2	7,30 c	7,30 c	7,70 bc	10,00 a	8,00 A
	Average (B)	7,80 B	7,50 B	7,80 B	9,30 A	
CV % = 9,10						
Leaf length (cm)	A1	23,60 ab	25,10 a	23,30 ab	23,10 b	23,70 A
	A2	23,10 b	23,20 b	19,90 c	21,20 c	21,80 B
	Average (B)	23,30 AB	24,10 A	21,60 C	22,10 BC	
CV% = 4,3						
Leaf width (cm)	A1	2,30 abc	2,70 a	2,40 ab	2,10 abc	2,30 A
	A2	2,30 abc	2,10 abc	1,70 c	1,80 cb	2,00 B
	Average (B)	2,30 A	2,40 A	2,00 A	1,90 A	
CV% = 5,70						
LAI (m² leaf/m² ground	A1	3,36 a	2,90 ab	1,93 cd	1,50 d	2,40 A
	A2	2,60 bc	1,90 cd	1,30 d	1,50 d	1,80 B
	Average (B)	2,90 A	2,40 B	1,60 C	1,50 C	
CV % = 18,10						

The leaf count per plant shows that the PN28 planting treatment at a density of 36 plants/m² exhibited the highest leaf count (10 leaves/plant), whereas other treatments ranged from 8.0 to 8.7 leaves/plant, with the lowest recorded in treatments A2B2 and A2B1 at 7.3 leaves/plant. This experiment indicates that planting density influences leaf number, and this difference is statistically significant at the 95% confidence level.

The impact of four planting densities and two Mizuna varieties at harvest time demonstrates that PN28 responds distinctly in terms of leaf count, specifically decreasing from 10 to 7.7 and 7.3 leaves/plant as planting density increases.

On average, planting density affects leaf count per plant of the two Mizuna varieties: at a density of 36 plants/m², the highest leaf count reached was 9.3 leaves; whereas at densities of 48, 72, and 108 plants/m², there were differences in leaf count per plant, but these were not statistically significant.

On average, plant variety did not influence leaf count per plant of the two Mizuna varieties. Similarly, on average, planting density did not affect leaf width of the two Mizuna varieties.

Leaf width criteria show that the widest leaves reached 2.7 cm in treatment A1B2, while the narrowest was 1.7 cm. Leaf width in the experimental treatments varied but did not show statistically significant differences.

Leaf Area Index (LAI) is a result that reflects the correlation between average leaf length, average leaf width, and planting density per square meter. The highest LAI (2.9 – 3.6 m² leaf/m² ground) was observed in treatments A1B2 and A1B1, while the lowest (1.3 – 1.5 m² leaf/m² ground) was in treatments A2B3 and A2B1. The remaining treatments showed differences in LAI but did not reach statistically significant differences at the 95% confidence level.

- **Low planting density (36 plants/m²):** PN28 exhibited he highest leaf count per plant (10 leaves). This could be attributed to the plants having sufficient space and light, allowing for maximum leaf development.
- **High planting density (48 – 108 plants/m²):** The leaf count decreased gradually from 8.0 to 8.7 leaves/plant, with the lowest at 7.3 leaves/plant (A2B2, A2B1). As planting density increased, plants had less space and light, leading to competition and reduced leaf count.
- **Decreasing leaf count with increasing planting density:** At high densities, PN28 showed a noticeable decrease in leaf count. This reflects a negative response of plants to high resource competition.
- **Impact of planting density:** At low density (36 plants/m²), the average leaf count per plant was 9.3, higher compared to other planting densities. However, the leaf count differences at densities of 48, 72, and 108 plants/m² were not statistically significant, indicating relative stability in leaf count within this range of densities.
- **Varietal factor:** It did not affect the average leaf count per plant of the two Mizuna varieties, suggesting similar responses of varieties to planting density conditions.
- **Differences in leaf width:** Leaf width ranged from 1.7 cm to 2.7 cm, with the widest observed in treatment A1B2. Despite differences, these were not statistically significant, indicating that leaf width is less affected by experimental factors.
- **Highest and lowest LAI results:** The highest leaf area index was observed in treatments A1B2, A1B1 (2.9 – 3.6 m² leaf/m² ground), and the lowest in A2B3, A2B1 (1.3 – 1.5 m² leaf/m² ground). This demonstrates a strong correlation between planting density and overall leaf area. Other treatments showed LAI differences but did not reach statistical significance, indicating the relative stability of LAI under certain experimental conditions.

Table 3: Impact of planting density on yield components and productivity of TN23 and PN28

Parameters	Variety (A)	Density (B)				Average (A)
		B1	B2	B3	B4	
Plant biomass (g/plant)	A1	24,66 ab	25,76 a	22,23 cb	23,87 ab	24,13 A
	A2	23,13 b	22,73 b	20,13 c	23,03 b	22,26 B
	Average (B)	23,90 A	24,25 A	21,18 B	23,45 A	
CV% = 5,4						
Theoretical yield (kg/0.1 ha)	A1	2.500 a	2.760 a	2.660 a	2.630 a	2.640 A
	A2	2.600 a	2.530 a	2.700 a	2.730 a	2.640 A
	Average (B)	2.550 A	2.650 A	2.680 A	2.680 A	
CV% = 13,54						
Actual yield (kg/0.1 ha)	A1	1840,70 a	1920,70 a	1402,70 bc	1324,00 bc	1622,00 A
	A2	1516,00 b	1530,00 b	1220,70 c	1204,00 c	1367,67 B
	Average (B)	1678,33 A	1725,33 A	1311,67 B	1264,00 B	
CV% = 8,25						
Commercial yield (kg/0.1 ha	A1	1480,67 b	1670,33 a	1182,33 d	1092,00 de	1356,33 A
	A2	1178,67 d	1337,33 c	1029,67 e	1059,93 e	1151,40 B
	Average (B)	1329,67 B	1503,83 A	1106,00 C	1075,97 C	
CV% = 4,75						

The data in Table 3 illustrate that planting density (B) and plant variety (A) influence the average plant weight, actual yield, and commercial yield of Mizuna at harvest time, with statistically significant differences at the 95% confidence level. On average, planting density affects the average plant weight of the two Mizuna varieties, with average weights ranging from 23.45 to 24.45 g/plant at densities B1, B3, and B4, and reaching 21.18 g/plant at density B2. This difference is statistically significant at the 95% confidence level.

Plant variety also influences the average plant weight, with TN23 exhibiting a higher average weight than PN28, and this difference is statistically significant at the 95% confidence level. However, variety did not affect the theoretical yield of the two Mizuna varieties, while planting density did have an effect on theoretical yield.

Planting density also affects the actual yield of the two Mizuna varieties, with yields ranging from 1678.33 to 1725.33 kg/0.1 ha at densities B1 and B2, and from 1264.00 to 1311.67 kg/0.1 ha at densities B3 and B4. This difference is statistically significant at the 95% confidence level.

Varietal factor influences the actual yield, with TN23 achieving higher actual yields than PN28, and this difference is statistically significant at the 95% confidence level.

Finally, variety influences the commercial yield of the two Mizuna varieties, with TN23 achieving higher commercial yields than PN28 (1356.33 kg/0.1 ha compared to 1151.40 kg/0.1 ha), and this difference is statistically significant at the 95% confidence level.

B1 and B2 densities resulted in higher actual yields (1678.33 – 1725.33 kg/0.1 ha) compared to B3 and B4 densities (1264.00 – 1311.67 kg/0.1 ha). This difference is statistically significant at the 95% confidence level, indicating that appropriate planting density can optimize actual yield. TN23 also achieved higher actual yields than PN28, with this difference being statistically significant at the 95% confidence level. This indicates that TN23 has greater production potential under specific planting conditions.

TN23 also achieved higher commercial yields than PN28 (1356.33 kg/0.1 ha compared to 1151.40 kg/0.1 ha). This difference is statistically significant at the 95% confidence level, indicating that TN23 not only has higher actual yields but also achieves a higher proportion of commercially acceptable products.

In summary, the results demonstrate that planting density and variety significantly affect various parameters of Mizuna cultivation, highlighting the importance of optimizing these factors to enhance yield and product quality in Mizuna production systems.

Conclusion

Planting density significantly influences the height development and leaf characteristics of Mizuna. At higher planting densities, plants tend to grow taller to compete for light, whereas at lower densities, plants develop more leaves due to ample space and sufficient light. This statistically significant difference underscores the importance of selecting appropriate planting densities to optimize crop development.

Both planting density and plant variety significantly impact the leaf count and Leaf Area Index (LAI) of Mizuna. Lower planting densities promote increased leaf count and larger leaf area, while higher densities lead to resource competition and reduced leaf count. Leaf width shows minimal sensitivity to these factors, highlighting its stability under experimental conditions. These results are crucial for determining the optimal planting density for Mizuna to achieve optimal growth.

Moreover, both planting density and plant variety significantly affect the average plant weight, actual yield, and commercial yield of Mizuna. Optimized planting densities can enhance average plant weight and actual yield, with variety TN23 demonstrating distinct advantages in average plant weight, actual yield, and commercial yield compared to PN28. These findings are of paramount importance for optimizing cultivation methods to achieve the highest productivity and quality for Mizuna.

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