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Quantitative Synergy of Seed Tuber Dimensions and Planting Density: Modeling Optimal Combinations for Maximizing the Productivity of Red Onion (Allium Ascalonicum L.) Bauchi Variety

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A B S T R A C T

Shallots (Allium ascalonicum L.) are a strategic horticultural commodity that faces challenges in improving productivity and farm efficiency due to decreasing returns to scale. This study focuses on optimizing cultivation through two critical factors: Seed Bulb Size, which determines initial vigor and the plant's food reserves, and Planting Density (spacing), which manages the intensity of intraspecific competition for nutrients and light. The scientific approach uses a Factorial Randomized Block Design (RBD) aimed at discovering a 'Quantitative Synergy' between these two factors, as treatment interactions have been shown to significantly affect Critical Yield Components, such as bulb diameter and bulb weight per clump. By making the Bauchi Variety the specific focus, the main objective of this study is to produce an Optimal Combination Modeling of Seed Tuber Dimensions and Planting Density. This prescriptive model is needed to fill knowledge gaps and provide precise and accurate cultivation protocols, thereby maximizing shallot productivity and ensuring farm efficiency. The experiment was carried out from March 30 to June 1, 2024, in Balonggebang Village, Gondang Subdistrict, Nganjuk Regency, at an altitude of approximately 59 meters above sea level, on Gromosal soil type. The experiment was conducted using a Randomized Block Design (RBD) consisting of two factors and three Blocks. Observations on plant height, number of leaves, and number of tillers were made every 14 days, while measurements of fresh plant weight, dry plant weight per clump, and dry tuber weight per plot were taken after harvest

INTRODUCTION

Shallots (Allium ascalonicum L.) are bulbous plants with fibrous roots, and their leaves are cylindrical, tapering at the tips, with a hollow interior. Shallot plants are widely cultivated in lowland areas with elevations between 10 – 250 meters above sea level. However, they can also be grown in mountainous areas at altitudes up to 1200 meters above sea level, although the bulbs tend to be smaller compared to those in lowland regions (Sunarjono, 1983).

Shallots (Allium ascalonicum L.) are a horticultural commodity that plays a strategic role in ensuring food security and the national economy. Although demand continues to rise, efforts to increase productivity are often hampered by efficiency issues. Shallot farming in many regions is reported to still be in a condition of decreasing returns to scale (Ngurah Arya et al., 2017), indicating that increasing the proportion of inputs does not always lead to a proportional increase in outputs. This situation necessitates scientific studies oriented toward agronomic precision strategies, with the main goal of maximizing yield per unit area while improving production efficiency. Research focused on optimizing the cultivation practices of specific varieties is key to ensuring the sustainability of this sector.

The methodological core of this research lies in the analysis of "Quantitative Synergy" through a Factorial Randomized Block Design (RBD). The factorial approach allows researchers to test interactions, that is, conditions where the effects of Seed Tuber Dimensions on yield can be amplified or suppressed depending on the Planting Density applied. Recent scientific journals have emphasized the importance of testing these interactions. For instance, studies by Suwandi et al. (2016) and Ahmad Bajo et al. (2025) demonstrated significant interactions between planting distance factors and the number of seeds per planting hole on various Critical Yield Components, including the number of tubers per clump, tuber weight per clump, and tuber diameter. Therefore, the most effective cultivation recommendations should be based on findings of synergistic treatment combinations, rather than merely individual effects.

The focus of this study is specifically directed at the Bauchi variety. The growth response and yield of shallot plants to cultivation management are highly dependent on the genotype (variety), in line with the principle of Genotype x Environment Interaction (G x E) (Nurjanani & Djufry, 2018; Fitriani et al., 2023). Different varieties have unique phenotypic responses to population density and varying initial vigor. Therefore, the results obtained from other varieties (such as Bima or Sanren) may not be directly replicable on the Bauchi variety. To provide a precise scientific contribution, this study does not stop at average comparisons but seeks to carry out Optimal Combination Modeling (Tesar, 1984).

Based on the background above, and considering the knowledge gap regarding the optimal combination of Seed Tuber Dimension and Planting Density quantitatively tested specifically for the Bauchi Variety, this research becomes essential. By utilizing the power of a Factorial RAK and quantitative analysis techniques, this study aims to test and model the synergy of these two factors. The results of this research are expected to provide prescriptive and accurate cultivation protocols for farmers, which will directly contribute to maximizing productivity and improving the quality of Red Onion (Allium ascalonicum L.) tubers of the Bauchi Variety at the research site.

LITERATURE RIVIEW

Achieving high productivity in red onion cultivation is strongly determined by two crucial management factors: the quality of planting material and the arrangement of growing space. First, the Bulb Seed Dimension is a direct indicator of the initial food reserves available, which is essential in determining the vigor of early vegetative growth and the development of the shallow root system (AAK, 2004). Second, Plant Density, which is controlled through planting distance arrangement, becomes a key determinant of the intensity of intraspecific competition. Optimal density should be able to balance maximizing the number of plants per unit area and minimizing severe competition among plants in acquiring nutrients, water, and sunlight (Tesar, 1984; Nugrahini, 2013).

METHODOLOGY

The research was conducted in Balonggebang Village, Gondang District, Nganjuk Regency. The research was carried out on paddy fields with Grumosol soil type, pH 6.5. The elevation is approximately 59 meters above sea level, and the research was conducted from March 30 to June 1, 2024.

The research was conducted factorially using a Randomized Block Design (RBD) with 2 factors and 3 replications. Factor I: seedling diameter (D), consisting of 3 levels; D1 = 1.4 – 1.61 cm (small), D2 = 1.62 – 1.81 cm (medium), D3 = 1.82 – 2.1 cm (large). Factor II: planting distance (J), consisting of 3 levels; J1 = 15 x 15 cm, J2 = 20 x 20 cm, J3 = 25 x 25 cm. From the two factors above, 9 treatment combinations were obtained, namely D1J1 = small tuber diameter with 15 x 15 cm planting distance, D1J2 = small tuber diameter with 20 x 20 cm planting distance, D1J3 = small tuber diameter with 25 x 25 cm planting distance, D2J1 = medium tuber diameter with 15 x 15 cm planting distance, D2J2 = medium tuber diameter with 20 x 20 cm planting distance, D2J3 = medium tuber diameter with 25 x 25 cm planting distance, D3J1 = large tuber diameter with 15 x 15 cm planting distance, D3J2 = large tuber diameter with 20 x 20 cm planting distance, D3J3 = large tuber diameter with 25 x 25 cm planting distance.

Observations were conducted non-destructively, with the following variables: (a) plant height, measured from the ground surface to the highest part, (b) number of leaves, which are leaves that have grown and are green, (c) number of shoots per clump of sample plants. Meanwhile, production observations were carried out at the pre-harvest stage, which included: (a) fresh weight of sample plants, (b) dry weight of sample plants (sun-dried), (c) dry weight of tubers per plot (sun-dried).

RESULT AND DISCUSSION

1. Plant Height.

The variance analysis results showed that there was no interaction between seedling diameter and planting distance on plant height at all observation ages. Seedling diameter affected plant height at 14, 28, and 42 days after transplanting (DAT), while planting distance affected plant height only at 14 and 28 DAT.

Table 1. Average Plant Height (Cm) for Seedling Diameter and Planting Distance Treatments at Various Observation Ages

Treatment	**Average plant height (cm) at age (days after planting)**			
	14	**28**	**42**	**56**
D_1	14,38 a	21,90 a	29,09 a	30,58 a
D_2	15,00 b	24,70 b	30,29 b	31,02 a
D_3	15,78 c	27,20 c	31,13 c	31,30 a
BNT 5%	**0,27**	**0,90**	**0,70**	**0,74**
J_1	14,82 a	23,20 a	30,00 a	30,73 a
J_2	14,96 a	24,78 b	30,07 a	31,00 a
J_3	15,38 b	25,80 c	30,40 a	31,10 a

Description : Angka-angka yang didampingi oleh huruf yang sama pada kolom yang The same shows no significant difference in the 5% BNT test.

Table 1 shows that the highest average plant height was achieved in the seedling diameter treatment of 1.82 – 2.1 cm (D3) at ages 14, 28, 42, and 56 days after planting. In the D1 treatment, the lowest average plant height was obtained; this is because the growth rate of plants is greatly influenced by the amount of food reserves contained in the tuber. Kuroiwo (in Sutopo, 1985) stated that larger or heavier seeds usually produce larger plant seedlings.

The effect of planting distance on plant height shows that the highest average plant height was achieved with the J3 treatment at ages 14, 28, 42, and 56 DAP. This is because the competition for obtaining life elements for the plants is not very intense. According to Setyati (1993), planting distance affects the competition among plants in utilizing light, nutrients, and water, which will influence growth by affecting the size of both the whole plant and its parts.

2. Number of Leaves

In the variance analysis, it can be seen that the interaction between the combination of seedling diameter treatments and planting distance on the number of leaves occurred at 42 days after planting. The seedling diameter treatment affected the number of leaves at all observation ages, while the planting distance treatment did not affect the number of leaves.

Table 2. The Effect of the Interaction Between Seedling Diameter and Planting Distance Treatments on the Number of Leaves at 42 Days After Planting

Mixing Treatment	Average number of leaves (sheets) at 42 DAP
D_1J_1	24,2 ab
D_1J_2	23,5 a
D_1J_3	24,3 ab
D_2J_1	28,7 c
D_2J_2	28,3 c
D_2J_3	29,1 c
D_3J_1	27,7 bc
D_3J_2	35,3 d
D_3J_3	29,6 c
BNT 5%	**3,95**

Note: Numbers accompanied by the same letter in the same column indicate no significant difference at the 5% BNT test.

Table 2 shows that the average number of leaves on the plants at 42 days after planting was highest in the combination of seedling diameter 1.82 – 2.1 cm and planting distance 20 x 20 cm (D3J2). This is because the larger the seedling, the more food reserves are available, and abundant food reserves will result in better plant growth. Meanwhile, a planting distance of 20 x 20 cm allows the plants to receive an optimal amount of sunlight—not too little and not too much. This will support the plants in producing a greater number of leaves.

Table 3 shows that the highest number of leaves was achieved with the large seedling diameter treatment D3. This is because the larger the tuber size, the more food reserves can be provided for seedling growth. Therefore, the larger the tuber, the better the plant growth, including the formation of a larger number of leaves.

Table 3. Average Number of Leaves Per Seedling Diameter Treatment at 14, 28, and 56 Days After Sowing

Treatment	**Average plant height (cm) at age (days after planting)**		
	14	**28**	**56**
D_1	7,51 a	17,10 a	26,73 a
D_2	8,69 b	19,16 a	29,84 b
D_3	10,96 c	23,56 b	33,36 c
BNT 5%	**0,98**	**3,06**	**2,33**
J_1	8,67 a	19,0 a	29,27 a
J_2	9,27 a	20,1 a	29,60 a
J_3	9,20 a	20,7 a	31,07 a

Note: Numbers accompanied by the same letter in the same column indicate no significant difference in the 5% BNT test.

3. Number of Tillers

Variance analysis results showed a significant interaction between the combination of seedling diameter treatment and planting distance on the number of tillers at 42 and 56 days after transplanting (DAT). Seedling diameter treatment affected the number of tillers at 14 and 28 DAT, while planting distance affected the number of tillers at 14 DAT. The effects of seedling diameter and planting distance can be seen in Tables 4 and 5.

Table 4. Effect of Interaction Between Seedling Diameter and Planting Distance Treatments on the Number of Tillers At 42 and 56 DAT

Mixing Treatment	**Average number of offspring at age (days after birth)**	
	42	**56**
D_1J_1	4,5 a	4,5 a
D_1J_2	5,2 ab	5,7 bcd
D_1J_3	5,3 abc	6,1 cde
D_2J_1	6,9 d	6,6 def
D_2J_2	4,6 ab	5,0 ab
D_2J_3	5,7 bc	6,9 ef
D_3J_1	5,3 abc	5,4 abc
D_3J_2	7,1 d	7,3 f
D_3J_3	6,3 cd	6,0 bcde
BNT 5%	**1,087**	**1,02**

Note: Numbers accompanied by the same letters in the same column indicate no significant difference at the 5% BNT test.

Table 4 shows that the highest average number of shoots was achieved with the D3J2 treatment combination. It is suspected that besides the large food reserves in the tubers resulting in many sprout eyes, the competition for utilizing sunlight, nutrients, and water is not intense. As the plant ages, the number of shoots formed also increases. This is in accordance with Bates (1934), who stated that the supply of dry matter in tubers is a factor influencing the formation of new shoots, where in large tubers the shoots produced are larger than those in small seedlings, because more food is available for growth.

Table 5. Average Number of Shoots for Seedling Diameter and Planting Distance Treatments at 14 and 28 Days After Planting

Perlakuan	**Average number of offspring (cm) at age (days after hatching)**	
	14	**28**
D_1	3,1 a	4,20 a
D_2	3,7 b	5,07 b
D_3	4,6 c	6,29 c
BNT 5%	**0,28**	**0,85**
J_1	3,6 a	5,18 a
J_2	3,8 ab	5,00 a
J_3	4,0 b	5,38 a

Note: Numbers accompanied by the same letter in the same column indicate no significant difference in the BNT 5% test.

Table 5 shows that the highest average number of shoots was achieved in the large diameter treatment D3 at 14 and 28 days after planting. This is because, at the initial growth stage, the formation of all plant organs is highly determined by the plant material for forming plant organs, namely the amount of food reserves in the tubers. Therefore, large tuber diameters (D3) produce more shoots. For the planting spacing treatment, the highest average number of shoots was achieved at the 25 x 25 cm planting spacing treatment (J3). This is due to less competition among plants for obtaining light, nutrients, and water compared to J1, resulting in more shoot growth.

3. Fresh Weight and Dry Weight of Plants per Cluster.

The analysis of variance results showed that there was no interaction between seedling diameter treatment and planting distance on the wet weight and dry weight of sample plants per clump.

Table 6: Average Wet Weight and Dry Weight of Sample Plants Per Clump Under Seedling Diameter and Planting Distance Treatments

treatment	**Wet weight of the plant (g) per clump**	**Plant dry weight (gr) per clump**
D_1	38,9 a	29,2 a
D_2	47,6 b	35,7 b
D_3	55,7 c	41,8 c
BNT 5%	**4,1**	**2,93**
J_1	44,5 a	33,4 a
J_2	47,9 ab	36,2 ab
J_3	49,8 b	37,3 b

Note: Numbers accompanied by the same letter in the same column indicate no significant difference at the 5% BNT test.

Table 6 shows that the treatment with larger diameters of 1.82 – 2.1 cm (D3) resulted in the highest fresh weight and dry weight per plant clump compared to the D1 and D2 treatments. This is because larger bulb diameters lead to better plant growth, meaning taller plants, more leaves, and a higher number of tillers. With better growth, production is also better, resulting in greater fresh and dry weight per plant clump. The average fresh and dry weight per plant clump under planting distance treatments was achieved with the J3 treatment (25 x 25 cm). This is because the competition among plants for sunlight, nutrients, and water is not intense, allowing the plants to utilize these growth factors well for better growth and production compared to using plant J1.

5. Dry Weight of Tubers Per Plot.

The variance analysis results indicate an interaction between the combination of seedling diameter treatment and planting distance on the dry weight of tubers per plot.

Table 7. Effect of the Interaction Between the Combination of Seedling Diameter Treatment and Planting Distance on the Dry Weight of Tubers Per Plot

Mixing Treatment	**Dry weight of tubers per plot (g)**
D_1J_1	1.215 a
D_1J_2	1.274 b
D_1J_3	1.223 a
D_2J_1	1.304 c
D_2J_2	1.393 d
D_2J_3	1.307 c
D_3J_1	1.313 c
D_3J_2	1.460 e
D_3J_3	1.408 d
BNT 5%	**31.5649**

Note: Numbers accompanied by the same letter in the same column indicate no significant difference in the 5% LSD test.

Table 7 shows that the D3J2 combination treatment produced a higher dry weight of tubers per plot. This is because the D3J2 combination treatment allowed the plants to grow better than the other combination treatments, and the plant population was neither too small nor too large. Consequently, the yield was also higher, with the highest dry weight of tubers (1,460 g).

CONCLUSIONS AND RECOMMENDATIONS

Based on the results and discussions above, it can be concluded that: (1) There is an interaction between seedling diameter treatment and planting distance on the parameters of the number of leaves at 42 days after planting, the number of tillers at 42 and 56 days after planting, and the dry weight of tubers per plot; (2) Seedling diameter treatment has a significant effect (p=0.05) on plant height at 14, 28, and 42 days after planting, the number of leaves at 14, 28, and 56 days after planting, the number of tillers at 14 and 28 days after planting, as well as the fresh and dry weight of sample plants per clump; (3) Planting distance treatment has a significant effect (p=0.05) on plant height at 14 and 28 days after planting, the number of tillers at 14 days after planting, as well as a significant effect on the fresh and dry weight of sample plants per clump; (4) The combination of seedling diameter and planting distance treatment D3J2 produces the highest dry tuber weight per plot, which is 1.46 kg.

FURTHER STUDY

This research still has limitations so that further research is needed on the topic of Quantitative Synergy of Seed Tuber Dimensions and Planting Density: Modeling Optimal Combinations for Maximizing the Productivity of Red Onion (Allium Ascalonicum L.) Bauchi Variety to perfect this research and increase insight for readers and authors.

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