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# The Role of Liquid Smoke and Biochar Planting Media on Shallot Growth and Production (Allium ascalonicum L)

**Seri Juni Yanti Harahap[1], Rasmita Adelina[2*)], Dini Puspita Yanty[3], Sutan Pulungan[4]**

[1,2,3,4]*Graha Nusantara University, Padangsidimpuan, Indonesia*
**Corresponding author: rasmita301271@gmail.com*

## Abstract

*Shallots (Allium ascalonicum L.) are a horticultural commodity with high sales value and a complete nutritional profile. This study was conducted in Padang Lawas Regency from February to April 2025. The research method is an experimental study, using a factorial randomized block design. The first factor is Liquid Smoke consisting of 3 levels, namely: A0 = Without giving liquid smoke, A1 = Liquid smoke 70 ml / L, A2 = Liquid smoke 90 ml / L. Factor II is the provision of rice husk biochar with soil consisting of 3 levels, namely: B0 = Without giving rice husk biochar B1 = rice husk biochar 210 gr / polybag, B2 = rice husk biochar 300 gr / polybag, The parameters observed are Plant Height (cm), Number of Leaves (strands), Number of Bulbs Per Clump (bulbs), Wet Weight of Bulbs Per Clump (grams), Dry Weight of Bulbs Per Clump (grams) and Bulb Weight Loss (%). The data obtained were analyzed using statistical analysis of variance followed by the Least Significant Difference Test (LSD). The results of the study showed that the application of liquid smoke significantly affected growth (plant height) in the early vegetative phase (14 days after planting) and significantly affected shallot production (number of bulbs per clump). The use of liquid smoke at a treatment level of 70 ml/L and biochar at a treatment level of 300 g/polybag produced the best results for shallot cultivation.*

***Keywords:*** *Shallot, Liquid Smoke, Biochar*

## 1. INTRODUCTION

Shallots (Allium ascalonicum L.) occupy a strategic position in global vegetable commerce and domestic culinary traditions, functioning simultaneously as essential seasoning agents and functional food ingredients with documented medicinal properties. Beyond their widespread use as a culinary flavoring, shallots demonstrate significant bioactive potential, serving as anti-inflammatory, antioxidant, and antiseptic agents with applications in traditional and modern pharmacology (B. S. Abidin, 2021). This multifaceted utility has established shallots as critical commodities within national agricultural and economic frameworks (Istina, 2016). According to Aryanta. (2019), the increasing demand for shallots correlates directly with the presence of bioactive secondary metabolites, including flavonoids, tannins, saponins, essential oils, kaempferol, flavonglycosides, frologlusin, dihydroalin, cyclhoalin, methialin, quercetin, polyphenols, and elemental sulfur concentrated within the bulb tissue (Aryanta, 2019). The comprehensive nutritional composition of raw shallots per 100 grams encompasses

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saturated fatty acids (0.089 g), monounsaturated fatty acids (0.011 g), polyunsaturated fatty acids (0.249 g), carbohydrates (16.80 g), protein (2.5 g), total fat (0.1 g), vitamin A (9 IU), vitamin B1 thiamine (0.20 mg), vitamin B2 riboflavin (0.11 mg), vitamin B3 niacin (0.7 mg), vitamin B6 pyridoxin (1.235 mg), vitamin B9 folate (3 µg), vitamin C (31.2 mg), calcium (181 mg), and iron (1.7 mg) (Bili, H.Y., Yuniwati, E.D & Rahayu, 2019).

The confluence of escalating population growth and diversifying dietary preferences has precipitated a sustained increase in the shallot demand trajectory. However, the persistent discrepancy between domestic production capacity and consumption requirements remains unresolved, necessitating continued import. This production-consumption gap manifests not exclusively in quantitative insufficiency but critically in temporal misalignment. The conventional cultivation cycle positions peak production during the dry season, whereas the monsoon period witnesses substantially reduced cultivation activity owing to heightened pathogenic pressure and disease incidence. Elevated seed costs during off-season periods, coupled with production volatility and subsequent market price fluctuations driven by product perishability, create significant economic constraints for producers. National shallot production data for 2023 documented 1,985,233 tons, representing a marginal increase from the 2022's 1,982,360 tons, with documented consumption reaching 2,861 kg per capita annually. In North Sumatra Province, production will reach 652,189 quintals by 2023. However, Padang Lawas District presents a considerably more constrained production profile, with recorded production data limited to 2021, documenting merely 235 quintals across 8.5 hectares, equivalent to 27.64 quintals per hectare, —substantially below the established production potential of 12-17 tons per hectare (Badan Pusat Statistik, 2022).

The multifactorial etiology underlying Padang Lawas's diminished shallot productivity encompasses suboptimal cultivation techniques, progressive soil fertility degradation resulting from sustained synthetic pesticide and fertilizer application, and substantial pest and disease pressures. Pathogenic incidence represents a critical constraint throughout the cultivation cycle from seedling establishment through harvest maturation to post-harvest storage phases. Strategic intervention through agricultural intensification, without chemical intensification, is a viable approach. The progressive elevation of societal consciousness regarding sustainable agricultural practices and the nutritional-health benefits of chemically uncontaminated agricultural products has catalyzed interest in organic cultivation methodologies (Kharisma, Y., Syahruddin., Darung, U., & Asie, 2021).

Liquid smoke, derived from the incomplete combustion (pyrolysis) of lignocellulose materials, constitutes a complex aqueous extract containing over 500 organic compounds with documented plant growth stimulation and disease resistance enhancement properties. The principal bioactive constituents included acetic acid (10.2%), phenolic compounds (4.13%), methanol, aldehydes, ketones, hydrocarbons, and pyridines. Acetic acid and methanol components facilitate accelerated plant growth through enhanced metabolic activity and cell division, whereas phenolic compounds and their derivatives function as antimicrobial agents and growth inhibitors at elevated concentrations. The functional versatility of liquid smoke encompasses its utilization as an organic fertilizer, bioinsecticide, plant growth stimulant, soil pH neutralizer, and a pathogenic suppressant. When applied at a concentration of 70 ml/L, liquid smoke demonstrated optimal efficacy in previous investigations of pepper cultivars, reducing fruit rot incidence while maximizing fresh fruit yield. When applied at 2% concentration every two days, liquid smoke substantially reduced aphid populations on chili pepper foliage. This evidence provides justification for investigating the potential of liquid smoke in shallot production systems (Made, S. dan Adryade, R, 2019).

Rice husk biochar, produced through controlled low-temperature pyrolysis (250-350°C) of agricultural residues, represents a sustainable approach for soil amendment and carbon sequestration. The physicochemical properties of rice husk biochar, —including elevated porosity, high cation exchange capacity, prolonged environmental persistence (residence time exceeding 1000 years), and capacity for sustained moisture and nutrient retention,—make it a superior alternative to conventional organic amendments. The elemental composition of rice husk biochar included silicon dioxide (52%), carbon (31%), potassium (0.3%), nitrogen (0.18%), phosphorus (0.08%), and calcium (0.14%), along with trace quantities of iron oxides, magnesium oxide, manganese, and copper. Biochar functions as an analogous system to natural zeolites, facilitating temporary nutrient storage, while enabling progressive nutrient availability to plant root systems. The amendment exhibited quantifiable enhancements in soil physical properties (structure, porosity, and drainage), chemical properties (nutrient availability and pH buffering), and biological properties (microbial habitat and diversity). Previous investigations have demonstrated that biochar amendment at 20 tons per hectare significantly improves subsurface water retention and positively influences shallot growth and yield parameters (Z. Abidin, 2021).

Despite accumulating evidence regarding the individual efficacy of liquid smoke and biochar as plant production inputs, few investigations have systematically examined their interactive effects within integrated shallot production systems. The synergistic potential of combining a biostimulant (liquid smoke) with a soil physicochemical modifier (biochar) remains largely unexplored within the specific context of bulb crop production. The present study addresses this knowledge gap by evaluating the interactive effects of liquid smoke concentration and biochar dosage on comprehensive growth and production parameters in shallot cultivation. This research initiative directly supports the district's agricultural intensification objectives while advancing knowledge applicable to sustainable production systems throughout tropical and subtropical regions (Panunggul, V.B., Rahayu, A.Y., 2021).

## 2. METHOD

The investigation was conducted in Pasar Sibuhuan Village, Barumun District, Padang Lawas Regency, North Sumatra Province, Indonesia (coordinates: 1°37'50.4'N, 100°31'45.2' E, elevation 260 m asl). The research site encompassed the well-drained Latosol soil characteristics of the region. The experimental period spanned from February to April 2025, encompassing the critical dry season when shallot cultivation exhibited maximum commercial viability. The geographic specification ensures climate consistency within documented precipitation patterns (300-500 mm tri-monthly) and temperature regimes (26-32°C ambient, 24-28°C nocturnal minimum).

This study employed a factorial randomized block design incorporating two independent variables: (1) liquid smoke concentration and (2) rice husk biochar amendment dosage. The experimental frame work was as follows:

Factor A - Liquid Smoke Concentrations:

$A_0$: Control (0 ml/L)

$A_1$: 70 ml/L

$A_2$: 90 ml/L

Factor B - Rice Husk Biochar Amendment:

$B_0$: Control (0 g/polybag)

$B_1$: 210 g/polybag

$B_2$: 300 g/polybag

The factorial combination generated nine treatment groups with three replications per treatment, establishing 27 experimental units arranged in a randomized block configuration with spacing parameters of 20 cm inter-plot and 10 cm inter-polybag distances. Each experimental unit was comprised of three plants with two designated sampling replicates, yielding a total population of 81 plants with 54 quantifiable sampling units.

Biological Materials: Shallot (Allium ascalonicum L.) cultivar Bima Brebes served as the experimental crop species. Seed bulbs were selected according to standardized criteria: uniform diameter (1.5 cm), single-bulb morphology, absence of mechanical damage or disease symptoms, and prior desiccation conditioning (2-4 months post-harvest).

Amendments and Soil Components: Rice husk biochar was produced via the controlled pyrolysis of milling residues obtained from regional rice processing facilities. Liquid smoke was procured from established agricultural suppliers using documented composition analysis. Potassium-enriched goat manure (120 g polybag) served as the baseline nutrient source. Latosol soil (collected from 0-20 cm depth) was composed of primary growth medium.

Equipment: Polybags (30 × 30 cm; 10-liter capacity), measuring devices (graduated cylinders, balances accurate to 0.01 g, rulers, measuring tapes), irrigation apparatus (watering cans), hand tools (shovels, hoes, stakes), and standard laboratory glassware for liquid smoke application.

Media Preparation (7 Days Pre-Planting): The Collected Latosol soil underwent initial processing, including vegetation removal, foreign material elimination, and homogenization. Potassium-enriched goat manure was incorporated in 120 g/polybag seven days prior to bulb transplanting to permit decomposition initiation. Rice husk biochar amendments were added to the media according to the treatment specifications, followed by thorough mixing to ensure uniform distribution. The prepared media were transferred to appropriately labeled polybags and allowed to equilibrate under ambient conditions.

Bulb Preparation and Transplanting: Shallot seed bulbs underwent apex removal (distal 1/3 portion), positioning the cut surface at the soil surface level post-transplantation, with superficial soil coverage. Transplanting operations were conducted during the afternoon hours (16:00-17:30) to minimize transplant stress. Single bulbs were placed at each planting location.

Liquid Smoke Application: Liquid smoke treatments were initiated one week post-transplantation and continued through harvest maturity. The application methodology consisted of soil surface application directly to the root zone at application rates of 15 ml per plant during the vegetative phase and 40 ml per plant during the generative phase administered every 48h. Foliar application was avoided to prevent potential phytotoxicity.

Maintenance Operations: Irrigation was administered twice daily (morning and evening, 06:00 and 16:00h) to maintain field-capacity soil moisture levels. Weeding operations were conducted biweekly or as required to prevent competition with established plants. Earthing-up operations were performed when bulb tissue emerged above the soil surface, ensuring complete bulb burial to maintain bulb blanching and prevent greening. Pest management relies exclusively on the inherent biocidal properties of liquid smoke without supplementary pesticide application.

Harvest Operations: Bulb maturity was assessed 60-70 days after transplanting using phenological indicators, including leaf yellowing (60-70% completion), petiolar collapse, and soil surface emergence cessation. Harvesting operations involved careful bulb extraction to prevent mechanical damage and data recording.

Plant Height (cm): Vertical distance measurements were conducted at four temporal intervals (14, 21, 28, and 35 days post-transplantation) using standardized rulers, measured from the soil surface to the apex of the longest leaf.

Leaf Number (helai/plant): Laminal counts were performed at identical temporal intervals (14, 21, 28, and 35 days post-transplantation) via direct visual enumeration of the fully expanded laminae.

Bulb Number per clump (bulbs/plant): Post-harvest bulb enumeration was conducted by manually counting the individual bulb units within each plant clump.

Fresh Bulb Weight per clump (grams): Immediately post-harvest, all aerial organs (leaves and roots) were excised, and soil residues were removed. Fresh biomass was quantified using calibrated balances accurate to 0.01 g.

Dry Bulb Weight per clump (g): Fresh bulbs underwent ambient air-drying for seven days prior to dry weight determination using calibrated analytical balances.

Bulb Weight Loss Percentage: Weight loss was calculated using the following mathematical expression: (Fresh Weight dry weight) / fresh weight × 100%, quantifying moisture loss during drying.

Quantitative data derived from observed parameters were subjected to univariate analysis of variance (ANOVA) employing a linear mixed-effects model: Y_{ijk} = μ + A_i + B_j + (AB){ij} + ε{ijk}, where Y_{ijk} represents the observations for liquid smoke treatment i and biochar amendment j in replication k, μ denotes the grand mean, A_i represents the effect of liquid smoke concentration, B_j signifies the biochar amendment effect, (AB){ij} quantifies the factor interaction, and ε{ijk} represents the residual experimental error. The significance threshold was set at $P<0.05$. Post-hoc pairwise mean comparisons were conducted using the Least Significant Difference (LSD) test at $\alpha=0.05$. Statistical analysis was performed using SPSS version 25.0 for Windows (IBM Corporation).

## 3. RESULTS AND DISCUSSION

### Results

Baseline soil analysis revealed substantial heterogeneity across the treatment combinations (Table 1). The nitrogen content ranged from 0.25% (A <ts> B <ts>) to 0.47% (A <ts> $B_2$), indicating baseline nitrogen insufficiency across all treatments. Available phosphorus demonstrated considerable variation, with minimum values of 4.08 ppm ($A_1B_0$) and maximum of 24.07 ppm ($A_2B_1$), suggesting phosphorus bioavailability inconsistencies. Exchangeable potassium concentrations ranged from 0.30 me/100g ($A_0B_0$) to 1.22 me/100g ($A_1B_1$), indicating potassium deficiency in control treatments.

Table 1. Soil Chemical Analysis Results for Treatment Groups

| Treatment | N (%) | P-Bray (ppm) | K-exch (me/100g) |
|---|---|---|---|
| $A_0B_0$ | 0.25 | 11.80 | 0.30 |
| $A_0B_1$ | 0.42 | 9.51 | 1.12 |
| $A_0B_2$ | 0.38 | 13.95 | 0.98 |
| $A_1B_0$ | 0.39 | 4.08 | 0.84 |
| $A_1B_1$ | 0.43 | 7.91 | 1.22 |
| $A_1B_2$ | 0.47 | 10.29 | 1.03 |
| $A_2B_0$ | 0.45 | 11.38 | 0.98 |
| $A_2B_1$ | 0.42 | 24.07 | 1.06 |
| $A_2B_2$ | 0.38 | 7.18 | 1.10 |

Analysis of variance indicated that liquid smoke application exerted statistically significant effects on plant height exclusively during the early vegetative phase (14 days post-transplantation, $p=0.023$), with insignificant effects at subsequent measurement intervals ($p>0.05$). Biochar amendment application demonstrated non-significant effects across all temporal intervals.

Table 2. Mean Plant Heights (cm) at 14 Days After Transplanting

| Treatment | Mean Height (cm) | Statistical Group |
|---|---|---|
| $A_0$ | 31.17 | a |
| $A_1$ | 29.63 | ab |
| $A_2$ | 28.92 | b |
| $A_0B_0$ | 31.74 | (optimal) |
| $A_1B_2$ | 29.13 | (suboptimal) |
| $A_2B_0$ | 27.12 | (minimal) |

Paradoxically, the control treatment ($A_0$: 0 ml/L) produced superior plant heights (31.17 cm) at 14 days post-transplanting, with progressive height reduction observed in treatments receiving liquid smoke application ($A_1$: 29.63 cm; $A_2$: 28.92 cm). This counterintuitive result contradicts the conventional expectations regarding biostimulant efficacy. Phenolic compounds present in liquid smoke, particularly at elevated concentrations (70-90 ml/L), likely induce earlystage growth inhibition through phytotoxic effects. According to Yatagai (2002), phenolic compounds exert concentration-dependent biphasic effects: stimulation at optimal concentrations and inhibition at elevated concentrations. The application of 70-90 ml/L likely exceeded the optimal concentration threshold during early plant development, when tissues exhibited heightened sensitivity to growth inhibitors.

At subsequent measurement intervals (21, 28, and 35 days post-transplantation), liquid smoke effects diminished to insignificance ($p>0.05$), suggesting temporal acclimation of plant tissues to the chemical environment or gradual degradation of inhibitory phenolic compounds. By day 35, treatment $A_1B_1$ (70 ml/L liquid smoke + 210 g/polybag biochar) produced maximal plant height (19.84 cm), indicating that the combined amendment approach provided compensatory benefits offsetting early-phase growth suppression.

The insignificant effect of biochar amendments on plant height throughout the experimental period aligns with the slow nutrientrelease kinetics of biochar. Biochar functions as a slow-release nutrient repository, gradually making the retained nutrients available through microbial decomposition and chemical weathering processes that require weeks to months for optimal functionality. The 35-day observation window was insufficient to reveal the maximum growth-enhancement potential of biochar.

Comprehensive variance analysis revealed non-significant effects of liquid smoke application, biochar amendment, and treatment interactions across all observation periods ($p>0.05$). However, consistent patterning emerged across all measurement intervals: treatment $A_1B_2$ (70 ml/L liquid smoke + 300 g/polybag biochar) produced the highest numerical leaf counts (31.89 leaves at 14 days; 11.78 leaves at 21 days; 23.56 leaves at 28 days; 26.89 leaves at 35 days), although these differences lacked statistical significance.

Table 3. Mean Leaf Numbers (helai) at Selected Observation Intervals

| Treatment | 14 DAT | 21 DAT | 28 DAT | 35 DAT |
|---|---|---|---|---|
| $A_0B_0$ | 29.78 | 10.56 | 21.22 | 26.78 |
| $A_1B_2$ | 31.89 | 11.78 | 23.56 | 26.89 |
| $A_2B_0$ | 23.89 | 8.44 | 15.44 | 16.67 |
| Mean | 27.30 | 9.88 | 19.28 | 24.17 |

The non-significant effects of treatment on leaf number production suggest that basic photosynthetic capacity and vegetative biomass allocation were not substantially enhanced by the amendments applied during the experimental period. The slightly elevated leaf numbers in the $A_1B_2$ treatment suggest incipient synergistic interactions, although the magnitude of the effect remained below the statistical significance threshold. The combination of moderate liquid smoke concentration (70 ml/L) and maximal biochar dosage (300 g/polybag) appears to provide numerically superior conditions for leaf development, potentially reflecting an optimal balance between growth stimulation and physical edaphic properties.

The biochar component may have enhanced soil water retention capacity and microbial activity, creating a more conducive environment for leaf expansion, whereas the 70 ml/L liquid smoke concentration may have provided growth-stimulatory effects (acetic acid and methanol) without reaching inhibitory phenolic thresholds. This interpretation aligns with previous investigations demonstrating that 70 ml/L represents the optimal liquid smoke concentration for horticultural applications.

The variance analysis indicated significant effects of liquid smoke application on bulb number ($p<0.05$), representing the most pronounced treatment effect observed in the entire investigation.

Table 4. Mean Bulb Numbers per Clump

| Treatment | Mean Bulbs | Statistical Group |
|---|---|---|
| $A_0$ | 8.31 | b |

| Treatment | Mean Bulbs | Statistical Group |
|---|---|---|
| $A_1$ | 13.25 | a |
| $A_2$ | 9.13 | b |
| $A_1B_2$ | 14.67 | (optimal) |
| $A_1B_1$ | 12.00 | (intermediate) |

The substantial increase in bulb numbers observed with $A_1$ treatment (70 ml/L liquid smoke) compared to control ($A_0$) and $A_2$ treatments reflects genuine stimulation of reproductive physiology. Liquid smoke application at a concentration of 70 ml/L concentration appeared to trigger developmental signals promoting bulb initiation and enlargement. The acetic acid and methanol constituents of liquid smoke presumably facilitated metabolic shifts from vegetative to generative development, optimizing resource allocation toward bulb biomass accumulation.

The submaximal response observed at 90 ml/L ($A_2$: 9.13 bulbs) relative to 70 ml/L ($A_1$: 13.25 bulbs) again demonstrates concentration-dependent biphasic effects characteristic of plant-active compounds. Beyond the optimal threshold of 70 ml/L threshold, phenolic inhibitor concentrations apparently exceeded tolerance thresholds, suppressing reproductive development previously stimulated at lower concentrations.

Variance analysis indicated significant effects of both liquid smoke application ($p<0.05$) and biochar amendment ($p<0.05$) on fresh bulb weight, with the interaction approaching significance ($p=0.063$).

Table 5. Mean Fresh Bulb Weights per Clump (grams)

| Treatment | $A_0$ | $A_1$ | $A_2$ |
|---|---|---|---|
| $B_0$ | 75.33 | 105.67 | 82.50 |
| $B_1$ | 84.00 | 128.33 | 95.00 |
| $B_2$ | 109.00 | 134.33 | 105.67 |
| Mean | 89.44 | 122.78 | 94.39 |

The $A_1$ treatment (70 ml/L) produced substantially elevated fresh bulb weights (122.78 g) compared to $A_0$ (89.44 g) and $A_2$ (94.39 g) controls, confirming that moderate liquid smoke concentration facilitated bulb expansion. The combination $A_1B_2$ (70 ml/L liquid smoke + 300 g/polybag biochar) produced maximal fresh weight values (134.33 g), representing a 50% increase over untreated controls. This substantial enhancement suggests a genuine synergistic interaction whereby biochar's soil physical-chemical improvements (enhanced water retention, improved nutrient availability) combined with biostimulant effects of liquid smoke optimize conditions for bulb development.

Variance analysis revealed significant effects of liquid smoke ($p<0.05$) and biochar ($p<0.05$) treatments on dry bulb weights, with a significant interaction effect ($p<0.05$). Dry weights were consistently lower than fresh weights by approximately 35-40%, reflecting substantial water loss during air desiccation.

Table 6. Mean Dry Bulb Weights per Clump (grams)

| Treatment | $A_0$ | $A_1$ | $A_2$ |
|---|---|---|---|
| $B_0$ | 45.67 | 63.00 | 49.50 |
| $B_1$ | 50.33 | 76.67 | 57.00 |
| $B_2$ | 65.33 | 80.33 | 63.67 |
| Mean | 53.78 | 73.33 | 56.72 |

## Discussion

The $A_1B_2$ treatment combination produced maximal dry weight (80.33 g), representing a 49% increase over control treatments, confirming that soluble solids accumulation (not merely water uptake) was enhanced by the combined amendment approach. This substantial increase in dry matter content suggests genuine metabolic enhancement rather than osmotic water imbibition (Rina et al., 2021).

Bulb Weight Loss Percentage

Weight loss during storage desiccation remained relatively consistent across treatment groups (35-40%), with minimal treatment-related variation, suggesting that amendment treatments did not substantially alter bulb tissue moisture characteristics or storage physiology.

The experimental results reveal a complex pattern of amendment interactions that partially align with theoretical expectations, while presenting unexpected findings that require mechanistic interpretation. The most striking result—significant enhancement of bulb number and weight at 70 ml/L liquid smoke concentration, with diminished responses at 90 ml/L—demonstrates concentration-dependent bimodal dose-response characteristics well-documented in plant biostimulant literature. This pattern reflects the dual nature of phenolic compounds: growth stimulation at physiologically compatible concentrations and phytotoxicity at inhibitory thresholds (Siregar, 2021).

The apparent paradox of initial height suppression followed by eventual enhanced bulb production at an identical 70 ml/L concentration reflects fundamental developmental physiology principles. During the early vegetative stages, phenolic growth inhibitors suppressed shoot elongation, presumably redirecting photoassimilates toward root and bulb development. As the bulbing phase commenced (weeks 4-10 of cultivation), the transition from vegetative to generative physiology transformed the growth inhibitors into reproductive stimulants, ultimately favoring the bulb number and size. This temporal reprogramming of developmental responses to identical chemical stimuli constitutes a sophisticated example of ontogenic shift in plant physiology (Suharyatun,, S. Warji. Haryanto., & A. Anam, 2021).

The biochar component contributed to enhanced growth parameters through multiple mechanisms: (1) improved soil physical structure facilitating root penetration and nutrient uptake, (2) enhanced water retention capacity supporting continuous nutrient transport and plant metabolic activity, (3) elevated soil pH buffering capacity, ameliorating any acidic effects of liquid smoke application, and (4) provision of microbial habitat supporting beneficial soil microorganisms that enhance nutrient cycling and plant health. The synergistic interaction between liquid smoke (a chemical growth regulator) and biochar (a physical-chemical soil modifier) produced superior outcomes relative to either amendment applied individually.

## 4. CONCLUSIONS AND SUGGESTIONS

This study systematically evaluated the interactive effects of liquid smoke and rice-husk biochar amendments on shallot growth and production under controlled experimental conditions. The central finding that the combined application of liquid smoke at 70 ml/L concentration with biochar at 300 g/polybag produced substantially enhanced bulb production parameters (50% weight increase, 38% bulb number increase relative to control treatments) provides evidence-based justification for integrated amendment protocols in shallot cultivation. While early vegetative growth parameters (plant height and leaf number) showed minimal treatment effects, the pronounced impacts on bulb production (the economically critical parameter) substantiated the practical value of this amendment approach. The concentration-dependent biphasic response to liquid smoke optimal effects at 70 ml/L and diminished effects at 90 ml/L underscores the necessity for precision in amendment application. The synergistic interaction between organic biostimulants and physical soil amendments represents an important direction for sustainable intensification of vegetable production systems. Future investigations should extend the observation period to capture long-term biochar effects, examine variable soil types and climatic conditions, and investigate the optimal timing of amendment application during the cultivation cycle. The implementation of these findings will contribute to agricultural sustainability objectives through reduced chemical input dependency while maintaining or exceeding yields achievable through conventional production methodologies. This approach holds promise for resource-limited producers seeking to enhance productivity within environmentally compatible frameworks.

## 5. ACKNOWLEDGE

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