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Effects of color shade-net on the growth and yield quality of garlic in the lowlands area

Izza Azkiya Rachma, Endang Sulistyaningsih*, and Valentina Dwi Suci Handayani

Department of Agronomy, Faculty of Agriculture, Universitas Gadjah Mada
Jl. Flora no. 1, Bulaksumur, Sleman, Yogyakarta 55281, Indonesia
*Corresponding author: endangsih@ugm.ac.id

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Abstract

Garlic is a bulbous plant that grows and produces super bulb yields in environments with temperatures between 15−25°C and humidity levels of 60−70%. A challenge in garlic growing in lowland areas is the suboptimal bulb growth caused by elevated air temperatures (23−37°C). Through experimentation with the 'Lumbu Putih' variety, predominantly cultivated at low elevations in Gunung Kidul Regency, the use of shade nets is anticipated to modify the microclimate, hence establishing optimal circumstances for garlic plant development. This research specifically targeted to identify the shade net colors that can alter the microclimate to optimize the development, productivity, and quality of garlic production. The study was performed in Logandeng Village, Playen District, Gunung Kidul Regency, Yogyakarta Special Region, at an elevation of approximately 215 meters above sea level. The treatments were organized according to a randomized complete block design (RCBD) including three levels: open land as a control, white shade nets, and black shade nets. Each treatment level comprised five replications organized as blocks. The data collected was analysed by analysis of variance (ANOVA) and the least significant difference (LSD) test at a significance threshold leaf number 5%. The findings indicated that the shade net treatment enhanced the leaf count, leaf surface area, plant growth rate, and dry weight per plant. The black shade net treatment yielded a good quantity of cloves and an increased bulb density relative to the white shade net. According to the findings of structural equation modeling (SEM) study, garlic production is directly controlled by the yield component of 96.2% and indirectly affected by the growth component of 88.3%. The yield and growth component factors that generate direct and positive contributions, as indicated by the Stepwise Multiple Regression analysis, include total root length, plant dry weight, bulb diameter, and clove number.

INTRODUCTION

Lumbu Putih is a national garlic variety originating from Gunung Kidul Regency, Yogyakarta, and is still farmed by the local farmer. Garlic cultivation in this region occurs from July to October to facilitate bulb initiation, which necessitates cold temperatures. In Indonesia, garlic thrives and achieves its optimum yield when cultivated at altitudes over 700 meters above sea level, with temperatures between 12−24°C (Rahayu et al., 2022). Nonetheless, in actual conditions, environmental alterations stemming from global warming affect daily temperature increases, leading to reduced bulb size in lowland regions. Limited efforts in technological application have been undertaken to enhance garlic cultivation in lowland regions, including the utilization of Gibberellin and Arbuscular Mycorrhizal Fungi (Setianto, 2022). The utilization of these technologies can enhance plant development but fails to facilitate the transport of assimilates to

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the sink organ, thereby impeding yield enhancement in lowland regions (Setianto, 2022).

Garlic bulbs arise via microscopic biochemical alterations and macroscopic physiological transformations, wherein phytohormones, phenolics, and allicin levels respond to light and temperature, influencing bulb development (Atif et al., 2020b). Numerous studies indicate that the initiation and translocation of assimilates to the garlic sink organ are influenced by microclimatic conditions, including temperature and light (Atif et al., 2019; Atif et al., 2020a; Atif et al., 2020b). Thus, it is imperative to use technologies that may establish more conducive environmental conditions for the growth of garlic.

One such approach is the manipulation of microclimates. Microclimatic conditions are affected by the physical attributes and environment around the land surface, which may be altered by land manipulation and modifications to the physical environment (Oke, 1987). The microclimate, seen a limiting factor for garlic growing in lowland regions, can be modified by technological application to better meet the growth requirements of garlic plants. Shade nets are a technological application applicable to environmental modification. The implementation of shade nets is anticipated to diminish light intensity, hence lowering temperature and enhancing humidity in the vicinity of the planting area. Rajasekar et al. (2013) conducted research indicating that shade nets mitigate abiotic stress by providing reduced light intensity and temperature, along with increased humidity, which subsequently influences the productivity and quality of various cultivated plants, including tomatoes, eggplant, chilies, cucumbers, radishes, spinach, and coriander.

Numerous research indicate that each plant has a distinct reaction to various colors of shade nets. The use of red shade nets on fenugreek plants (*Trigonella foenum-graecum* L.) led to enhanced measurements of plant height (25.59 cm), number of leaves (28.47), root length (8.64 cm), and fresh biomass (135.25 kg.100 m^{-2}) in comparison to yellow, white, blue, and green shade nets (Desai et al., 2017). Another study indicates that the use of white nets on cutleaf groundcherry (*Physalis angulata* L.) enhances stem height and diameter, branch quantity, and the weight, number, and size of fruits in comparison to open field conditions (Morales et al., 2018). So far, no research have been conducted on the effect of black and white shade nets on garlic crops in lowland regions. This research attempts to show how the color of shade nets might alter the microclimate to enhance the development and productivity of garlic plants in lowland areas.

MATERIALS AND METHODS

The research was carried out in July–October 2021 in farming land in Logandeng Village, Playen, Gunung Kidul, Yogyakarta at an altitude of ±215 meters above sea level, temperature of ±23–37°C, and humidity of ±45−75%. The planting material used was a garlic plants variety of Lumbu Putih Handayani from Gunung Kidul Regency. The research was arranged in a randomized complete block design (RCBD) with one factor consisting of three levels, which were open field as control, white shade net, and black shade net. The selection of net color was based on the color properties of the thread used in research conducted by Morales et al. (2018) and Sivakumar et al. (2018). Each level consisted of five repetitions as blocks. The shade net was installed in a rectangular shape with ventilation openings on the southern side (Figure 1). Seedlings were planted in experimental plots measuring 1 × 2.10 m^2 with production plots measuring 1 × 1.5 m^2. The planting space used was 10 × 10 cm^2 (175 plants per plot). Plant maintenance included watering, fertilizing, and controlling pests, diseases, and weeds. Garlic plants were harvested at 100 days after planting.

Observation of light interception, light intensity (lux), temperature (°C), and humidity (%) was carried out every week during the growing season in the afternoon (1 pm). Light intensity observation was made above the shade net and above the plant canopy using a Benetech GM1010 Digital Lux Meter (Shenzhen Jumaoyuan Science and Technology - Shenzhen, China). Light interception (LI) was calculated with the following equation:

$$LI\ (\%) = \left[1 - \frac{Qb}{Qt}\right] \times 100\% \quad ....(1)$$

LI is light interception, Qb is the radiation range that reaches the canopy surface, and Qt is the radiation range above the shade net (Portes and de Melo, 2014). Temperature and humidity were observed using OneMed HTC-2 thermo hygrometer (PT. Inti Medicom Retailindo – Gresik, Indonesia) by placing the sensor at a height of 1 meter above the ground surface in each experimental plot.

Disease incidence (%) was observed by counting

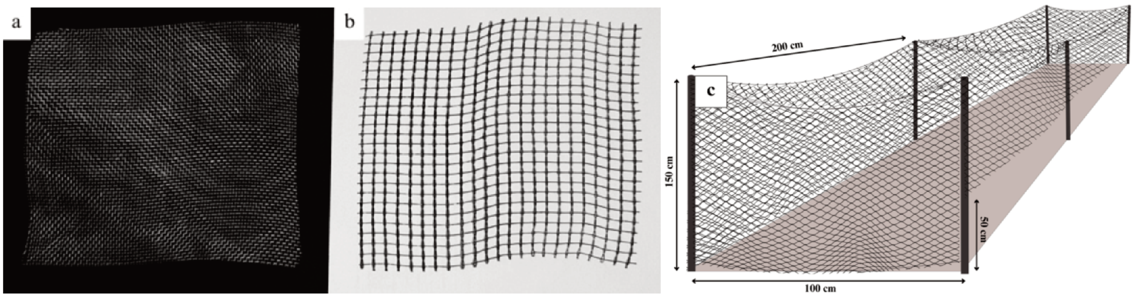

Figure 1. Knitting pattern (a; b) and design (c) of white shade nets and the commercial black net

the number of plants affected by the disease in each treatment plot when the plants were 10 WAP (weeks after planting). The incidence of the disease was calculated using the following formula:

$$DI\ (\%) = \frac{x}{n} \times 100\% \quad ....(2)$$

DI is the percentage of plant disease incidence, x is the number of plants affected by disease in the experimental plot, and n is the total number of plants in the observation plot (Y. Zhang et al., 2023).

Observations on the number of leaves, leaf area (cm^2), and total root length were carried out when the plants were 4, 8, and 12 WAP. Leaf area and total root length were carried out using an area meter (Delta-T Devices Ldt. Serial No. CB380495, 220 V, 50 Hz). Plant growth rate ($g.cm^2.week^{-1}$) and dry weight per plant (g) were carried out when the plants were 4, 8, and 12 weeks after planting (WAP). Plant growth rate was calculated using the following formula:

$$CGR = \frac{1}{Ga} \times \frac{W2\text{-}W1}{T2\text{-}T1}\ kg/m^2/week \quad ....(3)$$

Ga is land area (m^2), W is total dry weight of plants (grams), and T is time (weeks) (Gardner, 2008). There were several post-harvest variables observed, including bulb height, bulb diameter, number of cloves, and bulb density ($g.ml^{-1}$). Bulb height and diameter were observed using a caliper. Bulb density was calculated using the following formula:

$$Pd = \frac{Mt}{Vc} \quad ....(4)$$

Pd is the bulb density value ($g.mm^{-3}$), which is defined as the mass of particles occupying a certain unit volume, Mt is the bulb mass (g), and Vc is the bulb volume (mm^3) (Dalvand, 2011).

Data were analyzed using Analysis of Variance (ANOVA) at $\alpha = 0.05$. If there was a significant difference between treatments, a comparison test between means was performed using the LSD test. Structural equation modeling (SEM) analysis was carried out to determine the relationship model between constructs (latent variables). Stepwise multiple regression analysis was also used to determine plant variables that have a large and direct effect on yield. Analysis was performed using RStudio 2022.07.2+576 "Spotted Wakerobin" software and SmartPLS version 4.1.0.0 (4.1.0.0).

RESULTS AND DISCUSSION

Light interception, light intensity, air temperature, and humidity

The results indicated that different colors of shade nets possess distinct light interception capabilities (Table 1). The most light interception was seen in the black shade nets, averaging 24%, but the white shade nets attained only 14% (Fig. 2). The often utilized black shade nets cannot alter the spectrum quality of light (Arthurs et al., 2013). White shade nets has superior light-scattering capabilities in the upper visible light spectrum compared to other colored shade nets and absorb ultraviolet light (UVA+B) (Shahak, 2008; Goren et al., 2011). Increased light interception inside the shade net results in reduced intensity of transmitted sunlight (Table 1). The effect of shade nets on the intensity of sunlight reaching the planting area was evident during daytime measurements (Fig. 3a). The intensity of light absorbed by plants directly influences the efficiency of photosynthesis, encompassing the activities of carbon assimilation enzymes, stomatal opening, metabolite accumulation, and pigment composition, which indirectly impacts plant growth as a more intricate metabolic response that contributes to biomass accumulation (Shafiq et al., 2021; Zhang et al., 2022; Zhou et al., 2022).

Light is a crucial element in the production of

Table 1. Light interception, light intensity, soil temperature, air temperature, and relative humidity under different shade nets and open field

Treatment	Indicator				
	Light interception (%)	Light intensity (×10³ lux)	Soil temperature (°C)	Air temperature (°C)	Relative humidity (%)
Open field	0 c	112.60 a	30.92 a	37.42 a	42.83 b
White shade nets	14 b	85.94 b	29.10 c	35.67 c	46.10 a
Black shade nets	24 a	86.55 b	29.95 b	36.80 b	43.00 b
CV (%)	22.53	6.61	1.14	0.58	2.63

Remarks: The number within column followed same letters indicate no significant difference based on LSD test at α = 0.05

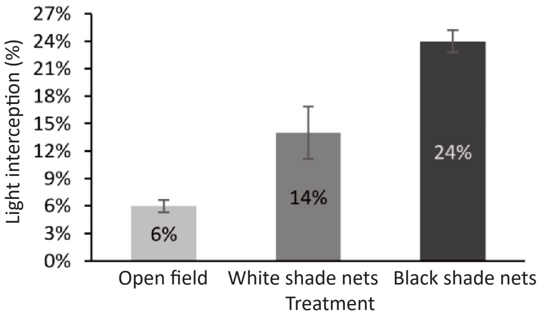

Figure 2. Light interception under different color shade nets and open field

photosynthates during the process of photosynthesis. Nonetheless, an overabundance of solar radiation does not invariably benefit plants. Garlic is classified as a C3 plant, often thriving with radiation levels of 600–900 μmol $m^{-2}.s^{-1}$, or 30–40% of full solar radiation (1,500-2,000 μmol $m^{-2}.s^{-1}$) during a standard growth season (Ilić and Fallik, 2017). Under open field circumstances, the mean light intensity throughout the day attained 112,600 lux (2,270.37 μmol $m^{-2}.s^{-1}$). Simultaneously, the mean light intensity beneath the white and black shade nets was 85,940 lux (1,591 μmol $m^{-2}.s^{-1}$) and 86,550 lux (1,602.77 μmol $m^{-2}.s^{-1}$), respectively. Excessive radiation energy can render plants vulnerable to photoinhibition, thermal stress, and stomatal closure, thus diminishing net photosynthesis, which is the primary source of glucose substrates for growth (Ilić and Fallik, 2017). Conversely, increased light interception via the use of shade nets may lead to diminished yields due to insufficient light exposure.

The use of shade nets not only influences light intensity in the cultivation zone but also alters micro-environmental factors, including temperature and humidity in the vicinity of the planting area (Table 1). The application of shade nets reduced soil and air temperatures by 0.97°C and 0.62°C for black shade nets, and by 1.82°C and 1.75°C for white shade nets (Fig. 3b; Fig. 3c). Photosynthesis is a thermally sensitive process, with photosystem II identified as the most heat-sensitive component. An increased ratio of open photosystem II and enhanced photochemical efficiency contribute to the improved maintenance of the photosynthetic rate (Zhou et al., 2022). Furthermore, the use of black and white shade nets may elevate humidity levels by 0.40% and 7.63%, respectively (Fig. 3d). The utilization of shade nets can alter light intensity by diminishing radiation intensity and modifying the thermal characteristics of the microclimate, consequently elevating the ratio of water vapor to air volume, which results in an increase in relative humidity (Chia and Lim, 2022; Ilić et al., 2017). Humidity is essential for the process of photosynthesis. Plants will undergo less water evaporation if the surrounding humidity is sustained at an optimal level. Consequently, the plant will maintain its stomata in an open state. Carbon dioxide will be sequestered, and the plant's temperature may be regulated by evaporation. Photosynthesis remains feasible at ideal light levels if the stomata are maintained in an open state. Reducing plant transpiration at elevated light levels is crucial for maintaining open stomata (Chia and Lim, 2022).

The use of shade nets in various colors and thread configurations is recognized to induce varying

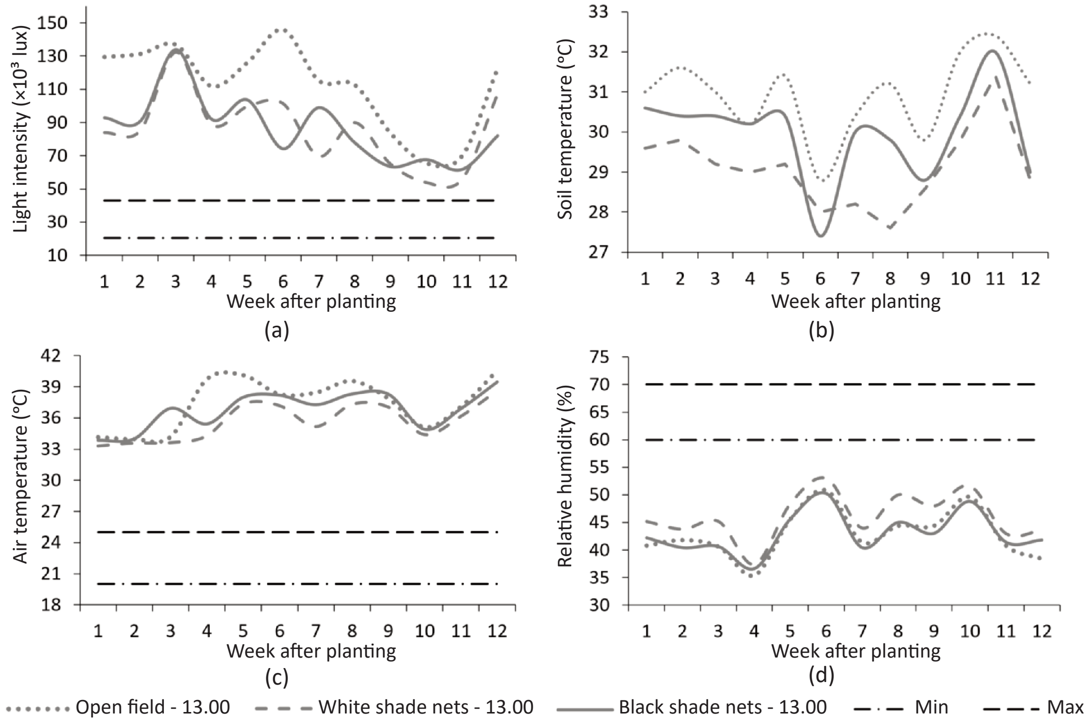

Figure 3. The fluctuation pattern of light intensity (a), soil temperature (b), air temperature (c), and relative humidity (d) under different color shade nets in comparison to open field

air temperature swings during the afternoon and evening. The variation in air temperature changes during the afternoon and evening across all treatments suggests that the reradiation process or outgoing radiation is affected by the treatment. Greater changes in air temperature of 4.44°C were seen beneath the black shade net, in contrast to 2.81°C under the white shade nets (Fig. 3c). This results from the interplay of two characteristics of the net: a pronounced shading effect of the black shade nets and relatively large apertures in the shade net, facilitating efficient warm air removal through enhanced ventilation (Tanny, 2013).

Disease incidence

The disease triangle concept elucidates how a disease can emerge and progress when there is a connection between a vulnerable plant and a virulent pathogen inside an environment conducive to pathogen proliferation or one that is unfavorable for the plant. The disease triangle concept in plant pathology emphasizes the interplay of pathogens, plants, and the environment (Velásquez et al., 2018). The occurrence of Fusarium wilt disease in garlic is attributable to the prior cultivation of shallots in the same area, which was infected by Fusarium. *Fusarium* sp. is a soilborne pathogen prevalent in the soil and frequently linked to plant roots (Ekwomadu and Mwanza, 2023). Fusarium can persist in sterile soil for as long as 17 years in the absence of a host plant (Soesanto et al., 2022). Environmental determinants affecting illness transmission including temperature and humidity. The application of shade nets presents two potential outcomes: (i) enhancing crop yields by reducing disease prevalence or (ii) worsening disease occurrence due to alterations in the environment that promote pathogens (Liebig et al., 2019). This research indicates that the use of black shade nets can reduce the percentage of disease incidence relative to white shade nets. The humidity beneath the white shade net exceeds that behind the black shade net. Elevated humidity creates favorable circumstances for the survival and dissemination of Fusarium (Deltour et al., 2017).

The greatest proportion of disease incidence was seen in the open field, followed by the white shade net, and subsequently the black shade net (Fig. 4). The increased disease incidence in the open field at 10 weeks after planting likely resulted from adverse environmental conditions for garlic plants, but the increased disease incidence behind white shade nets can be attributed to the conducive conditions that promote disease proliferation. In open field circumstances, the adverse microclimate caused by

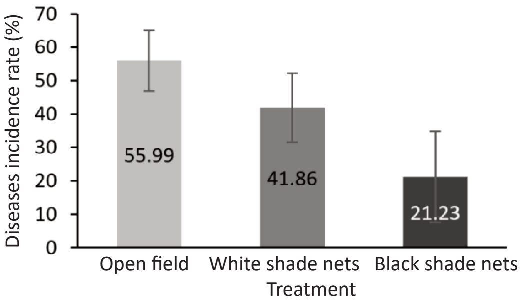

Figure 4. Effects of different color shade net on disease incidence at 10 WAP

white and black shade nets, which generate elevated light intensity and warmth, leads to unsatisfactory garlic growth. This state is exacerbated by diseases such as Fusarium, which can endure severe temperatures (Baruah et al., 2025).

The interaction of soil temperature, air temperature, and relative humidity, coupled with a reduction in temperature on the plant surface, can promote dew formation in the cultivation area (Liebig et al., 2019). The circumstances lead to a greater prevalence of disease under white shade nets (41.86%) compared to black shade nets (Fig. 4). Elevated humidity levels enhance the probability of pathogen proliferation, resulting in diminished plant viability and reduced agricultural yield (Talley et al., 2002; Velásquez et al., 2018). The life cycle of Fusarium could continue for an extended period as a saprophyte in the soil, subsisting by decomposing host cells to extract nutrients (Velásquez et al., 2018). Fusarium infection in plants induces leaf epinasty, wilting, chlorosis, necrosis, abscission, and leaf mortality, leading to the disruption and impairment of the transport system for water and mineral nutrients from the roots to all plant parts (Ekwomadu et al., 2023; Rosmini et al., 2021). This results in badly afflicted plants wilting and perishing, while those that endure will exhibit stunted growth and diminished productivity.

Number of leaves and leaf area

During the vegetative phase, assimilates will be preserved in vegetative organs, such as leaves and roots, but during bulbs formation phase, assimilates will be stored in sink organs, such as bulbs. Simultaneously, leaf area is a characteristic that affects the effectiveness of photosynthetic activities in plants (Evans, 1993). A broader leaf cross-section correlates with increased photosynthate production. Plants cultivated under shade nets have an increased leaf area due to enhanced cellular development in low light intensity (Ilić et al., 2017). The application of shade net significantly affected the leaf number at 12 weeks after planting (WAP) (Fig. 5a) and the leaf area at 8 WAP (Fig. 5b). Under open field circumstances, prolonged high temperatures resulting from intense radiation from the sun might interfere with plant metabolic activities and cell division, thereby affecting leaf area and number of leaves (Ahemd et al., 2016; Flaishman et al., 2015).

The leaf area index significantly influences the assimilation rate and net photosynthesis. The increased leaf area is attributable to light, which serves both as a source of photosynthetic energy and as a mediator of photomorphogenesis (Liu, 2012). Broad and expansive leaves are a reaction of plants to low light intensity conditions. In broader leaves, the cells enlarge to capture more light, hence optimizing the photosynthesis process. Additionally, the use of white and black shade nets can mitigate physiological burns on the leaves, resulting in a smaller decrease in leaf area until the time of harvest. The reduction in leaf area may result from physiological burns at the leaf tips (sunscald) in certain plants, attributable to elevated leaf temperature conditions (Jenni and Yan, 2009). This relates to the ideal heat dissipation procedure that transpires on the broader and bigger leaf surface. A bigger leaf surface area increases the extent of the surface available for heat dissipation, hence mitigating physiological burns on the leaves. Furthermore, a reduction in leaf area may result from the abscission of leaves affected by pathogens (Ekwomadu and Mwanza, 2023).

Plant growth rate and plant dry weight

The growth rate and dry weight of plants are significantly affected by fluctuations in light intensity due to the utilization of different colored shade nets.

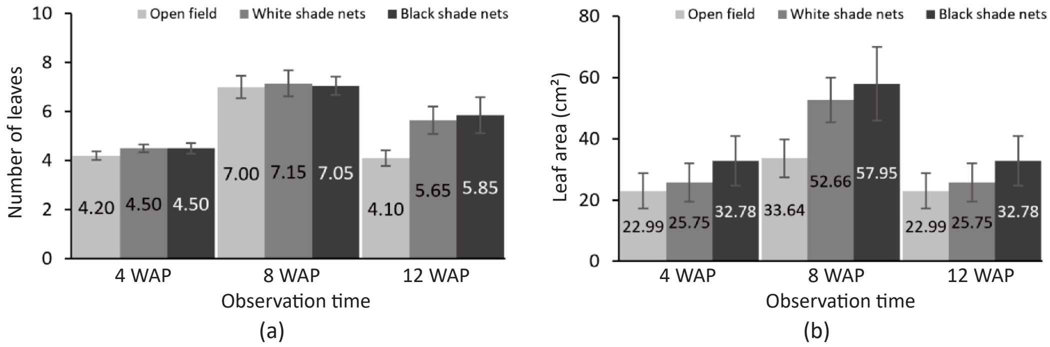

Figure 5. Effects of color shade nets on the number of leaves (a) and leaf area (b)

Figure 6. Garlic plants grown under colored shade nets (a. white; b. black) and in the open field (c. control)

In contrast to black shade nets, brightly colored shade nets, particularly white, are observed to enhance vegetative growth and leaf robustness, including plant height, width, and leaf count in coriander (*Coriandrum sativum*), parsley (*Petroselinum crispum*), and basil (*Ocimum sanctum*) (Ilić and Fallik, 2017). The rate of plant growth will affect the accumulation of assimilates, as indicated by the dry weight per plant.

During the 4−8 week after planting (WAP) period, the growth rate of plants in open fields and behind white shade nets was much superior to that observed under black shade nets (Fig. 7a). The quantity of leaves produced increased despite a decreased leaf area, resulting in an enhanced growth rate of the plant (Leyva et al., 2015). Conversely, at 8−12 weeks after planting, the growth rate of plants behind black shade net surpassed that of those under white shade net and in open field conditions. This increase affected the dry weight per plant at 12 weeks after planting. Similar effects occur in wheat, where an enhanced growth rate influences the dry weight per plant at the end of the growing season (Alemu, 2018). Plants subjected to white shade nets exhibited a more pronounced decrease in growth rate compared to those receiving other treatments. The reduction in growth rate may be attributed to a fall in leaf quantity and a substantial reduction in leaf area, as leaves are crucial for the assimilation generated during photosynthesis (Weraduwage et al., 2015). Photosynthesis is a physiological mechanism responsible for the buildup of biomass in plants (Rosmini et al., 2021).

At 8 WAP, the dry weight per plant under black shade nets exhibited reduced yields in comparison to those in the open field and under white shade nets (Fig. 7b). Plants behind the black shade nets had the greatest increase in dry weight per plant relative to those in open fields and those under white shade nets. This suggests that the elevated growth rate of plants during 8−12 weeks after planting affects the dry weight per plant at 12 weeks after planting. An increase in the growth rate of wheat plants correlates with a rise in dry weight per plant after the end of the growing season (Alemu, 2018). Photosynthate generated by plants is stored in certain regions, including leaves, roots, and bulbs. Consequently, it may be inferred that enhancing plant output can be achieved by augmenting the physiological processes within the plant.

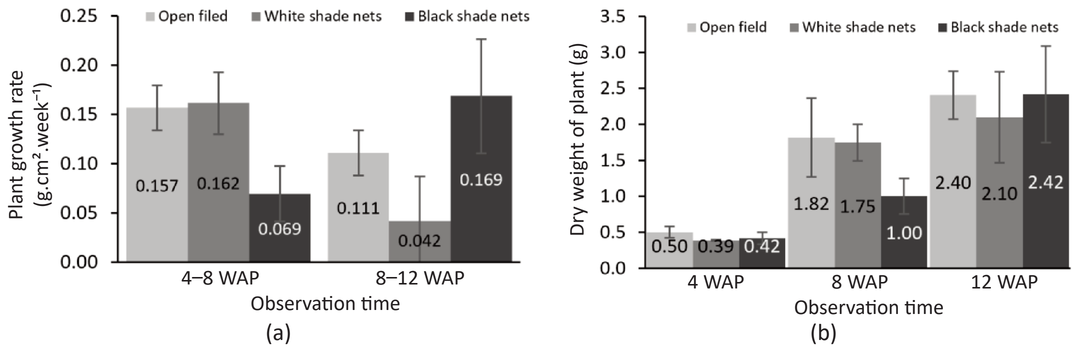

Figure 7. Effects of the color shade nets on (a) the plant growth rate and (b) the dry weight of the plant

Number of cloves and bulb density

The plants cultivated under black shade nets yielded considerably more bulbs than those in the open field and those under white shade nets (Table 2). The use of shade nets effectively enhanced bulb density relative to open field conditions (Table 2). Bulb density indicates the ratio of bulb weight to its volume. A higher bulb density value corresponds to increased bulb density. Light intensity and temperature significantly affect sugar buildup in plants (Ilić and Fallik, 2017). Exposure to elevated temperatures, reaching the optimal threshold of 25°C, particularly during fruit cell division and ripening, results in an augmentation of total soluble solids content attributable to heightened activity of carbohydrate biosynthetic enzymes and enhanced transpiration (Atif et al., 2020b; Guillén et al., 2007). This may correlate with increased bulb size and a greater number of cloves (Fig. 8).

Conversely, temperatures that beyond acceptable thresholds can impede the rate of photosynthesis and alter the process of assimilate translocation, resulting in suboptimal density of sink organs, such as bulbs. The production of garlic bulbs results from microscopic biochemical alterations and macroscopic physiological transformations, wherein the concentrations of phytohormones, phenolics, and allicin react to light and temperature, contributing to garlic bulb growth (Atif et al., 2020b). Certain studies indicate that bulb initiation and the transfer of assimilates to the sink organs of garlic are influenced by microclimatic variables, such as temperature and light (Atif et al., 2019; Atif et al., 2020a; Atif et al., 2020b). This pertains to the denaturation of alliinase enzyme production present in the leaves and bulbs of garlic at elevated temperature settings (Hasrianda and Setiarto, 2022). Consequently, it is essential to modulate solar radiation intensity using shade nets to diminish light intensity, soil temperature, and air temperature, thereby optimizing plant development and crop quality. Regulating microenvironmental conditions is essential for enhancing garlic output in lowland regions.

Structural equation modeling (SEM) approach to the impact of color shade-net use

Plant physiology is frequently influenced by both internal and external factors. Both elements play distinct roles in the process of plant growth and development. Internal determinants originate from the plant itself, commonly known as genetic factors, whereas external variables arise from outside the plant, typically referred to as environmental factors. Environmental considerations encompass

Table 2. Effects of color shade nets on the number of cloves and bulb density

Treatment	Number of cloves		Bulb density ($g.ml^{-1}$)
	8 WAPs	12 WAPs	12 WAPs
Open fields	7.15 a	10.90 b	0.63 b
White shade nets	7.50 a	10.60 b	0.99 ab
Black shade nets	8.25 a	12.10 a	1.31 a
Average	7.63	11.2	0.98
CV (%)	13.14	6.93	28.15

Remarks: The number within column followed same letters indicate no significant difference based on LSD test at α = 0.05

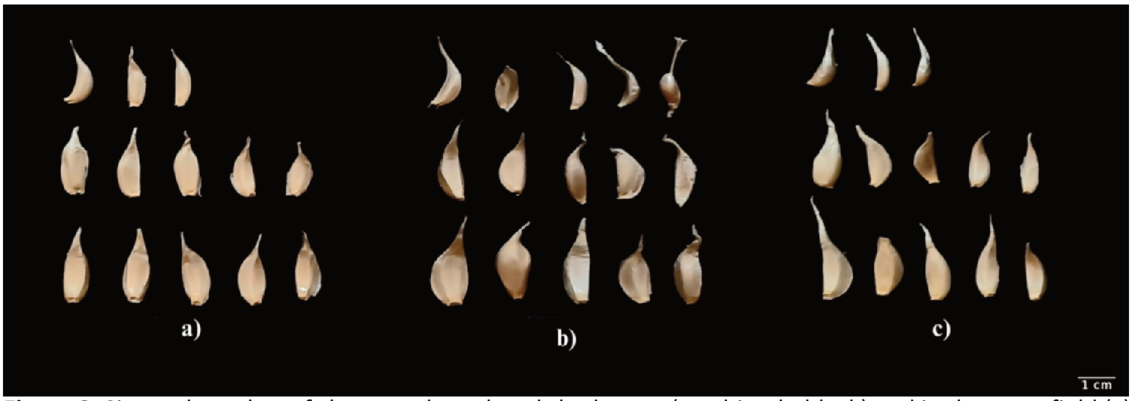

Figure 8. Size and number of cloves under colored shade nets (a. white; b. black) and in the open field (c)

plant microclimate conditions, including sunlight intensity, temperature, humidity, and the presence of disease in the vicinity of the planting location. The microclimate significantly influences the development and yield of garlic.

A conceptual model may be created a priori to elucidate the probable mechanisms behind the interaction among shade, microclimate, plant production, pests, and diseases, drawing from existing literature and research (Liebig et al., 2019; Rahman et al., 2021). The Structural Equation Model (SEM) inquiry was conducted based on the concept that microclimate factors, disease, growth components, and yield components greatly impact garlic production. The structural models were assessed for goodness of fit using predictive coefficient relevance (Q^2) prior to their application in elucidating the link between microclimate and plant development (Iriany et al., 2021). The computation yielded a Q^2 of 99.86% (Table 3). The model demonstrated a predictive relevance value of 99.86%, effectively accounting for 99.86% of the data's variability, indicating that 99.86% of the information inside the data could be elucidated by the model. The residual 0.14% was attributed to error and other factors not accounted for by the model. The created structural models most effectively elucidated the interaction among microclimates, illnesses, growth, and yield of garlic plants.

Garlic production is considerably and directly affected by the yield component, which amounts to 96.2%, which involves four explanatory factors: bulb diameter, number of cloves, bulb height, and bulb water content (Fig. 9) (Table 4). A condition demonstrating that bulb diameter, clove quantity, bulb height, and bulb moisture content significantly affect garlic productivity. Moreover, productivity is substantially and indirectly affected by the growth component, which accounts for 88.3% of the yield component, comprising five explanatory factors: total root length, number of leaves, leaf surface area, plant growth rate, and dry weight per plant (Fig. 9) (Table 4). Consequently, understanding the garlic plant's sensitivity to microenvironmental circumstances is essential for effective crop management (Fig. 9). The growth components were considerably and directly affected by the presence of disease by 79.4% (Fig. 9) (Table 5). The elevated prevalence of disease due to Fusarium oxysporum infection adversely impacted plant growth parameters. Impaired plants exhibited symptoms such as withering, necrosis, abscission, and mortality. The pathogen distributes systemically via the vascular system, resulting in the deterioration of plant roots and crowns, therefore impeding water and nutrient absorption (Koyyappurath et al., 2016). This suggests that the severity of the disease affecting the plants has an indirect impact on garlic yield.

Table 3. The goodness of fit test for the structural models

	Coefficient of determination (R^2)	Predictive relevance (Q^2)
Diseases	0.034	0.998
Growth component	0.874	
Yield component	0.828	
Yield	0.932	

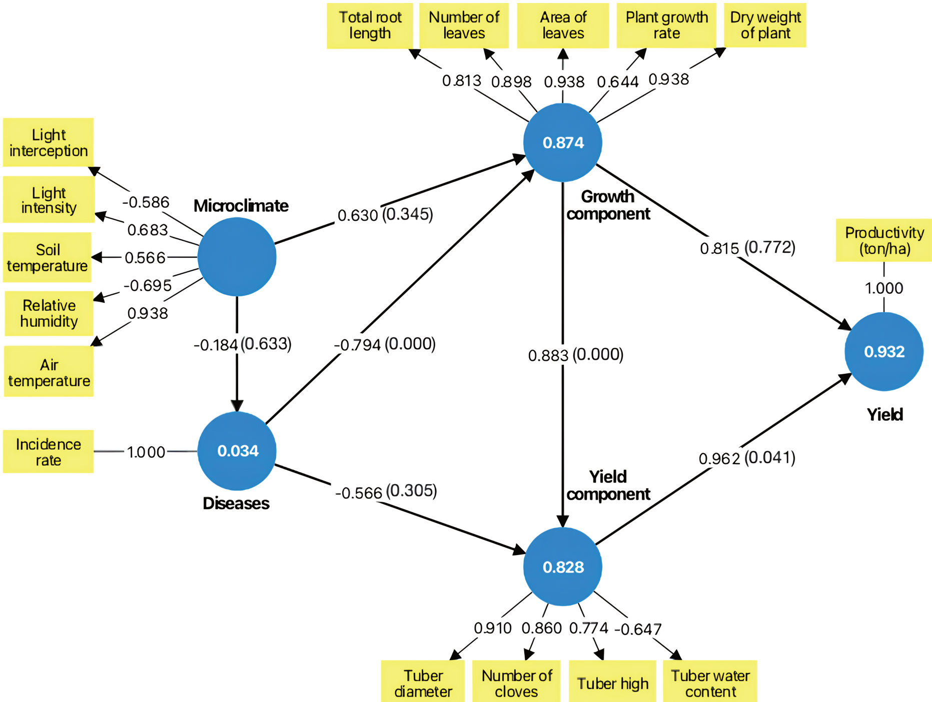

Figure 9. Structural equation modeling (SEM) revealing the overall (direct and indirect) effects of diverse factors (microclimate, diseases, growth components, yield component, and yield) on garlic

Remarks: Estimated path coefficients (direct effects) and significance are placed alongside each path. Coefficient of determination (R^2) is placed in the blue circle represents the latent variable with an arrow pointing to the circle.

Table 4. Summary results for the reflective construct of the measurement models

Construct	Indicator	Outer loading value	Description	Cronbach's alpha	Composite reliability	Average variance extracted
Microclimate	Light interception	-0.586	Invalid	0.089	0.764	0.499
	Light intensity	0.683	Invalid			
	Soil temperature	0.566	Invalid			
	Relative humidity	0.695	Invalid			
	Air temperature	0.938	Valid			
Diseases	Incidence rate	1.000	Valid	1.000	1.000	1.000
Growth component	Total root length	0.813	Valid	0.902	0.924	0.728
	Number of leaves	0.898	Valid			
	Area of leaves	0.938	Valid			
	Plant growth rate	0.644	Invalid			
	Dry weight of plant	0.938	Valid			
Yield component	Tuber diameter	0.910	Valid	0.291	0.846	0.646
	Number of cloves	0.860	Valid			
	Tuber high	0.774	Valid			
	Tuber water content	-0.647	Invalid			
Yield	Productivity	1.000	Valid	1.000	1.000	1.000

Remarks: The average variance extracted (AVE) values confirm the model validity, with AVE values over 0.5 for every variable used in the model (Muhaimin et al., 2020).

Table 5. Bootstrapping result

Path	Sample mean (M)	STDEV	T-Statistic	P-value	Significance
Microclimate → growth component	0.282	0.282	0.531	0.945	No
Microclimate → diseases	-0.248	0.384	0.478	0.633	No
Diseases → growth component	-0.626	0.196	3.589	0.000	Yes
Diseases → yield component	0.387	0.355	1.026	0.305	No
Growth component → yield	-0.076	0.539	0.290	0.772	No
Growth component → yield component	1.191	0.330	3.548	0.000	Yes
Yield component → yield	1.029	0.538	2.047	0.041	Yes

$$Y = -0.100 + 0.001*X1 + 0.138*X2 + 0.053*X3 + 0.046*X4 \quad ...(5)$$

Remarks: Y = yield; X1 = total root length; X2 = dry weight of plant; X3 = bulb diameter; X4 = number of cloves.

The factors affecting plant development and yield components that directly effect yield may be identified by multiple regression analysis employing the stepwise technique. The structural equation findings indicate a R^2 value of 95.7% and a p-value of 0.000 (eq. 5). The production of garlic is directly affected by total root length, dry weight per plant, bulb diameter, and clove count (eq. 5). These characteristics positively influence garlic productivity. This signifies that the augmentation of each variable will result in enhanced plant productivity. The overall root length is mostly influenced by root hairs, which significantly contribute to the absorption of water and nutrients from the soil (Murphy, 2015). A more broad plant root system correlates with increased nutrient absorption efficiency. Plants utilize absorbed water and nutrients in the process of photosynthesis. The augmentation of dry weight per plant signifies the effectiveness of photosynthetic outcomes (Wayan et al., 2020). The accumulation of assimilation and translocation to the sink organ will result in an increase in the diameter and quantity of cloves in garlic (Desta et al., 2021).

CONCLUSIONS

The microclimate conditions beneath the black shade nets resulted in a disease incidence rate of 49.26% for the plants, which is lower than that seen under the white shade nets. The use of shade nets for environmental modification enhanced leaf quantity, leaf surface area, plant growth rate, and dry weight per plant. Plants cultivated under black shading nets yielded a greater quantity of cloves and increased bulb density compared to plants produced under white shade nets. The Structural Equation Modeling research indicates that garlic productivity is directly impacted by the yield component at 96.2% and indirectly affected by the growth component via the yield component at 88.3%. The factors that directly and substantially influence productivity, as indicated by the Stepwise multiple regression analysis, are total root length, dry weight per plant, bulb diameter, and number of cloves.

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