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Research article

Clove Position on the Induction of Single-Clove Garlic, Yield, and Bioactive Compounds

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Abstract: Garlic is a valuable crop renowned for its medicinal properties and nutritional value, widely consumed in raw and processed. In Thailand's garlic production system, common garlic predominates, while single-clove garlic represents a smaller portion but commands higher prices due to its elevated levels of bioactive compounds and associated health benefits, leading to increased market demand. Research indicates that planting smaller cloves may enhance single-clove garlic production. Garlic cultivation in Thailand is primarily concentrated in the northern and northeastern regions, with only 1-2% of the production area dedicated to single-clove garlic. This study aimed to increase single-clove garlic yields by comparing different clove positions to optimize production and bioactive compound content, providing practical guidance for farmers. The experiment involved two treatments: inner cloves (0.5-0.8 g) and outer cloves (0.8-1.1 g). Yield components and bioactive compounds were analyzed. Results showed that outer cloves produced 100% common garlic bulbs, while inner cloves yielded 98.4% common bulbs and 1.6% single-clove garlic. Despite higher fresh yields of common bulbs from outer cloves, inner cloves produced 40.56 kg/ha of single-clove garlic. Weight loss after 30 days was 41–42% for common bulbs and 54.73% for single-clove garlic. Single-clove garlic showed more significant reductions in bulb and neck diameter. Notably, single-clove garlic contained the highest allicin content (35.79 mg/g FW) and DPPH inhibition (30.51%), indicating superior antioxidant properties. These findings suggest that planting inner cloves effectively promotes single-clove garlic production with enhanced bioactive properties, offering valuable insights for farmers.

Keywords: Single-clove garlic; Clove position; Allicin; Antioxidant; Bulb

1. Introduction

Garlic (*Allium sativum* L.) is an economically important vegetable, widely consumed in Thailand and globally. It is a herbaceous plant with nutrient-rich cloves that form an underground bulb. Garlic cloves contain major bioactive compounds, primarily organosulfur compounds such as allicin, alliin, and S-allyl-cysteine [1-2]. Allicin is a compound derived from the conversion of alliin. The synthesis of allicin in garlic plants is highly complex. The primary pathway begins with the roots absorbing sulfur compounds from the growing medium in the form of sulfate, which is then transported to the chloroplasts in the leaves for the synthesis of glutathione. This process ultimately leads to the production of alliin. The alliin is then transported to the cytoplasm of organelles responsible for food storage, where it is converted into allicin by the enzyme alliinase, stored in vacuoles [3-4].

Allicin, a key compound in garlic, is formed when garlic is crushed, leading to various biological activities that contribute to its therapeutic potential. It exhibits significant antioxidant properties linked to its ability to modulate reactive oxygen species (ROS), which are implicated in various diseases. Allicin has been shown to lower blood glucose levels and enhance insulin sensitivity, making it beneficial for managing diabetes. Moreover, consumption of garlic, rich in allicin, may confer protective effects against conditions such as cardiovascular diseases and cancer [5-7].

In Thailand, garlic consumption includes domestically produced garlic, with small, pungent cloves used in households and processed products, and imported garlic, featuring larger cloves typically used in restaurants and industrial settings. The main garlic production areas are in the northern and northeastern regions, where farmers prefer growing native garlic varieties with small cloves due to their strong, pungent aroma and their ability to thrive in Thailand's environmental conditions. The physical characteristics of garlic are closely related to the environmental and geographical factors of its growing regions [8]. Studies using DNA fingerprinting techniques, such as RAPD and microsatellite analysis, on garlic from cultivation areas in Thailand have revealed distinct patterns of genetic variation based on regional farming practices. In northern Thailand, farmers often practice rotational planting, introducing seed cloves from different sources. This has led to genetic diversity and the naming of varieties based on their place of cultivation, such as Chiang Mai, Pai, and Nam Pat varieties. In contrast, farmers in the northeastern region, such as in Sisaket, tend to manage and reuse seed cloves within their own farms, without introducing new genetic material from external sources. This practice results in high genetic similarity within the local garlic population [9-10].

In production, research suggests that inner cloves can promote the formation of single-clove (solo) garlic [11], which comprises only 1-2% of total production This variety is particularly prized for its higher antioxidant properties and commands a premium price. It is often used for pickling, as its strong odor is attributed to higher sulfide content [7-8,12-14]. Additionally, garlic is now commonly processed into black garlic, a method aimed at enhancing the concentration of key bioactive compounds, thereby increasing its value and positioning it as a health-oriented product [15].

Garlic cloves naturally sprout into new plants under favourable conditions. Farmers use these cloves for planting, with new cloves forming around the central flower stalk (scape) and developing in layers. Outer cloves are formed earlier, and typically larger than inner cloves [16]. Garlic bulbs are mainly composed of water and carbohydrates, with fructans as the primary carbohydrate. Garlic also contains proteins, pectin, minerals, and polyamines. The growth phase before bulb formation is crucial for determining bulb yield and size, as leaves play a significant role in accumulating carbohydrates via photosynthesis [17]. Factors influencing bulb size include varietal characteristics and optimal harvest timing, as clove formation is affected by environmental conditions such as temperature and day length. These factors impact phytohormone levels and other components of bulb growth [17-19]. Desta *et al*. [20] found that larger cloves increase yields, bulb size, and clove number, while smaller cloves, which accumulate fewer nutrients, may lead to single-clove garlic formation.

Thus, this research aims to identify the appropriate garlic clove position that induce the production of single-clove garlic, increasing its yield and bioactive compounds. The study will provide guidelines for farmers to optimize single-clove garlic cultivation.

2. Materials and Methods

2.1 The effect of clove position in garlic seed bulbs on single-clove garlic formation

The experiment utilized Thai garlic from Chiang Mai variety, characterized by thin outer skins, purple-red or light pink hues, and a strong aroma. Garlic bulb were divided into two treatments: outer cloves (0.8-1.1 g) and inner cloves (0.5-0.8 g), with the latter located near the central scape (Figure 1). Clove sizes within each group were uniform. A randomized complete block design (RCBD) with six replications, each containing 60 plants planted in loam soil, was implemented (Figure 3). The drip irrigation system was used with a planting distance of 20 × 20 cm along the drip lines. To control weed growth, appropriate pest management practices were employed. Water was provided based on the growth stages of the garlic and adjusted accordingly: 3-5 days per irrigation cycle during the early growth stage, 5-7 days per cycle after 30 days of planting, and 7-10 days per cycle during the bulbing stage. Watering was ceased 10 days before harvest. Fertilizer was delivered through the irrigation system. At 30 and 45 days after planting, a 15-15-15 NPK fertilizer was applied at a rate of 300 kg/ha. During the bulbing stage at around 60 days, a 13-13-21 NPK fertilizer was applied at a rate of 300 kg/ha every 14 days for two applications, along with foliar fertilizer sprayed. Harvesting occurred when leaf tips dried, brown leaves outnumbered green ones, and 110-120 days had elapsed [14]. The data collected included the ratio, fresh weight, and dry weight of garlic bulb types. Dry weight measurements were taken 30 days post-harvest to assess weight loss and calculate the weight loss percentage of the garlic plants [21]. Statistical differences were analyzed by using IBM SPSS Statistics. Means were compared at a 95% confidence level. The experiment was conducted at the Agricultural Innovation Research, Integration, Demonstration, and Training Center, Faculty of Agriculture, Chiang Mai University, Thailand, during the winter season from November 2022 to March 2023. The average temperature recorded during the experiment ranged from 20°C to 25°C (Figure 2).

$$\text{Weight loss}(\%)=\frac{(\text{fresh weight} - \text{weight after curing})}{\text{fresh weight}} \times 100$$

Figure 1. Characteristics of garlic bulb and clove: A normal garlic bulb consists of multiple cloves. The outer cloves refer to the cloves encircling the outermost layer of the bulb, while the inner cloves are located closer to the scape in the axial position (a). In contrast, a single-clove bulb (or solo bulb) lacks lateral cloves, containing only a single, unified clove (b).

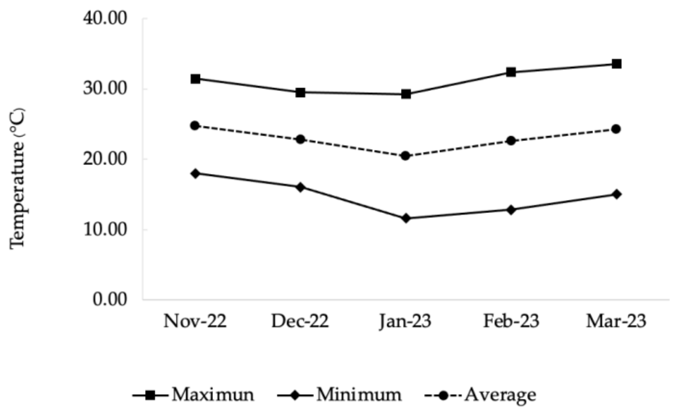

Figure 2. Temperature recorded during the experiment from November 2022 to March 2023.

2.2 Analysis of the active compound content and antioxidant activity in garlic

The active compounds were analyzed from dry garlic cloves (Figure 3). Allicin content was determined following a modified protocol from Zhu *et al*. [22], with HPLC analysis (Agilent 1260 Infinity II) performed according to modified methods from Bocchini *et al*. [23] and DPPH scavenging activity was analyzed following modified methods from Wongsa *et al*. [24]

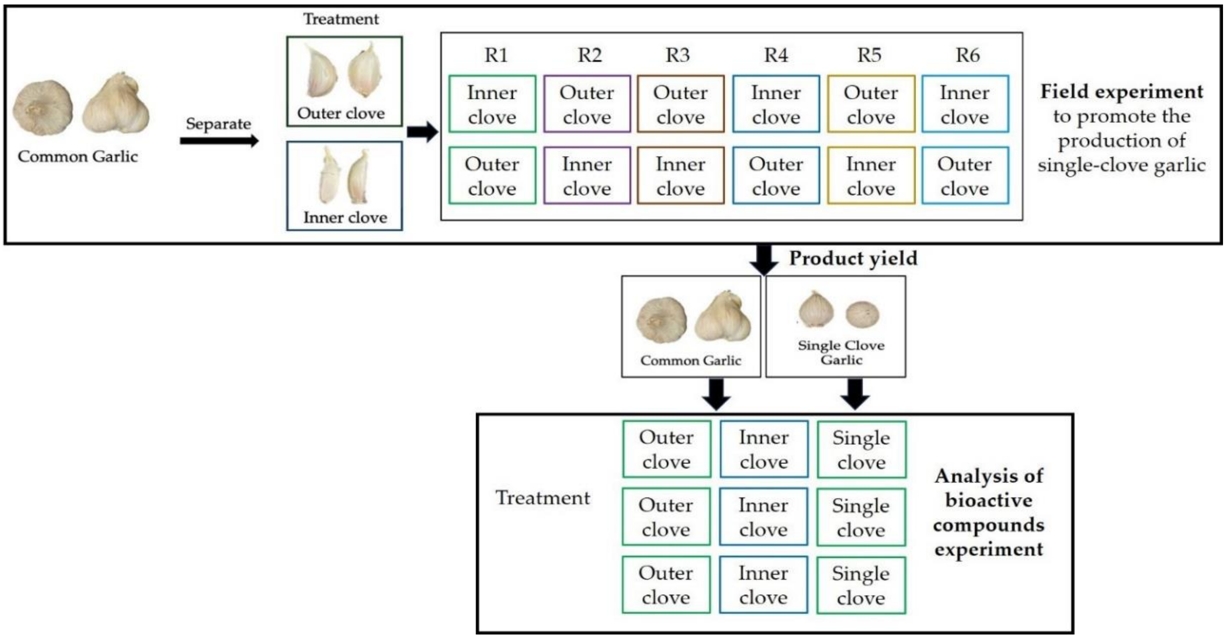

Figure 3. Schematic diagram of the experimental design.

3. Results

3.1 Mother clove position in garlic seed bulbs on single-clove garlic formation

Harvest yield analysis based on planted clove proportion. The harvest yield analysis revealed that garlic grown from outer cloves achieved a total bulb count of 85.00%, all of which were classified as normal bulbs (100.00%). In contrast, garlic grown from inner cloves produced a total bulb count of 84.17%, with 98.40% developing into normal bulbs. A significant difference was observed in the proportion of normal bulbs between these two groups ($P \leq 0.05$). Notably, garlic grown from outer cloves did not produce any single-clove bulbs, whereas inner cloves yielded 1.6% single-clove bulbs (Table 1, Figure 4). The fresh weight yield of normal garlic bulbs from outer cloves were 14,653.25 kg/hectare and 12,970.25 kg/hectare form inner cloves, with no statistically significant difference. However, inner cloves produced significantly more single-clove bulbs (40.56 kg/hectare) compared to outer cloves (0 kg/hectare). The total yields, including both normal and single-clove bulbs, were 14,653.25 kg/hectare for outer cloves and 13,011.81 kg/hectare for inner cloves, with no statistically significant difference ($P \leq 0.05$) (Table 1).

Table 1. The average percentage of total bulbs, normal bulbs, single-clove bulbs, total fresh yield weight, and total marketable weight with harvesting day.

Mother clove Position of normal bulb	Total bulb (%)	The ratio of normal bulb (%)	The ratio of single clove (%)	Fresh yield weight of normal bulb (kg/ha)	Fresh yield weight of single clove (kg/ha)	Total marketable weight (kg/ha)
Outer clove	85.00	100.00 a	0.00 b	14,653.25 a	0.00 b	14,653.25
Inner clove	84.17	098.40 b	1.60 a	12,970.25 b	40.56 a	13,010.81
T-test	ns	*	*	*	*	ns
CV (%)	10.46	1.01	10.93	23.09	26.36	23.14

Mean within the same column followed by different letters significantly differed between treatments at $P \leq 0.05$.
ns = no statistically significant difference
* = statistically significant difference ($P \leq 0.05$)

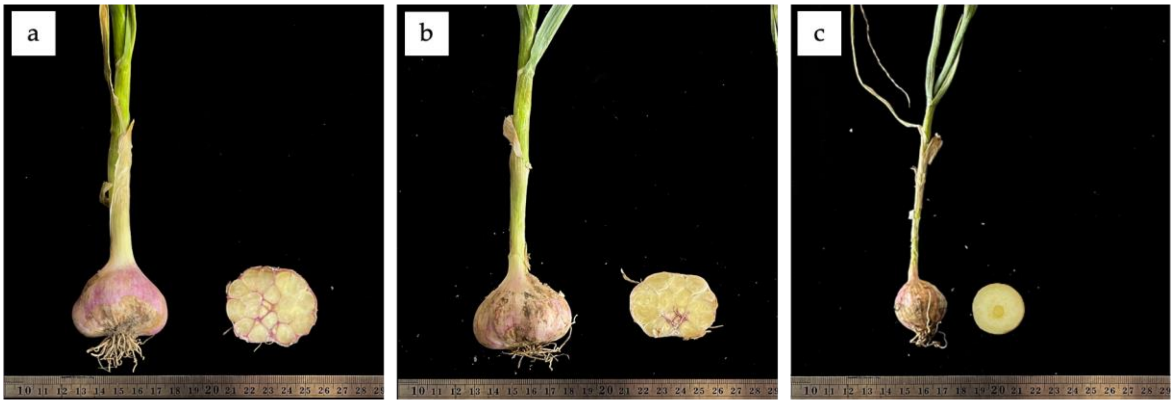

Figure 4. Characteristics of garlic bulbs obtained from planting: normal bulb from the outer clove (a); normal bulb from the inner clove (b); and single-clove bulb from the inner clove (c).

The weight of normal bulbs obtained from mother plants with outer and inner cloves showed no statistically significant difference after harvesting and air-drying. The initial weight of normal bulbs from mother plants with outer and inner cloves was 32.98 g and 29.69 g, respectively. The weight decreased from harvest to week 4 (30 days after harvest), reaching 19.31 g and 17.23 g, respectively. This represents a weight loss of 41.47% and 42.40%, respectively (Table 2). Single-clove garlic from inner cloves weighed 19.79 g after harvesting and 17.46 g after drying, with a weight loss of 53.73% (Table 3 and Figure 5). However, the dry weight yield of single-clove garlic decreased by more than 50% compared to multi-clove (normal) garlic.

Table 2. Bulb weight of normal garlic after harvest (-ing), weight after drying, and weight loss percentage.

Bulb type	Bulb weight after harvest (g/bulb)	Bulb weight after 30 days drying (g/bulb)	Bulb weight loss (%)
Normal bulb of outer clove	32.98	19.31	41.47
Normal bulb of inner clove	29.69	17.23	42.40
T-test	ns	ns	ns
CV (%)	23.09	25.18	5.83

Mean within the same column followed by different letters significantly differed between treatments at P≤0.05.
ns = no statistically significant difference

Table 3. Bulb weight of single-clove garlic after harvest (-ing), weight after drying, and weight loss percentage.

Bulb type	Bulb weight at harvest (g/bulb)	After drying at 30 days (g/bulb)	Bulb weight loss (%)
Single clove of outer clove*	—	—	—
Single clove of inner clove	05.63	02.53	53.73

* The data did not detect single-clove garlic from outer clove.
This table presents the average data for single-clove garlic without any statistical analysis.

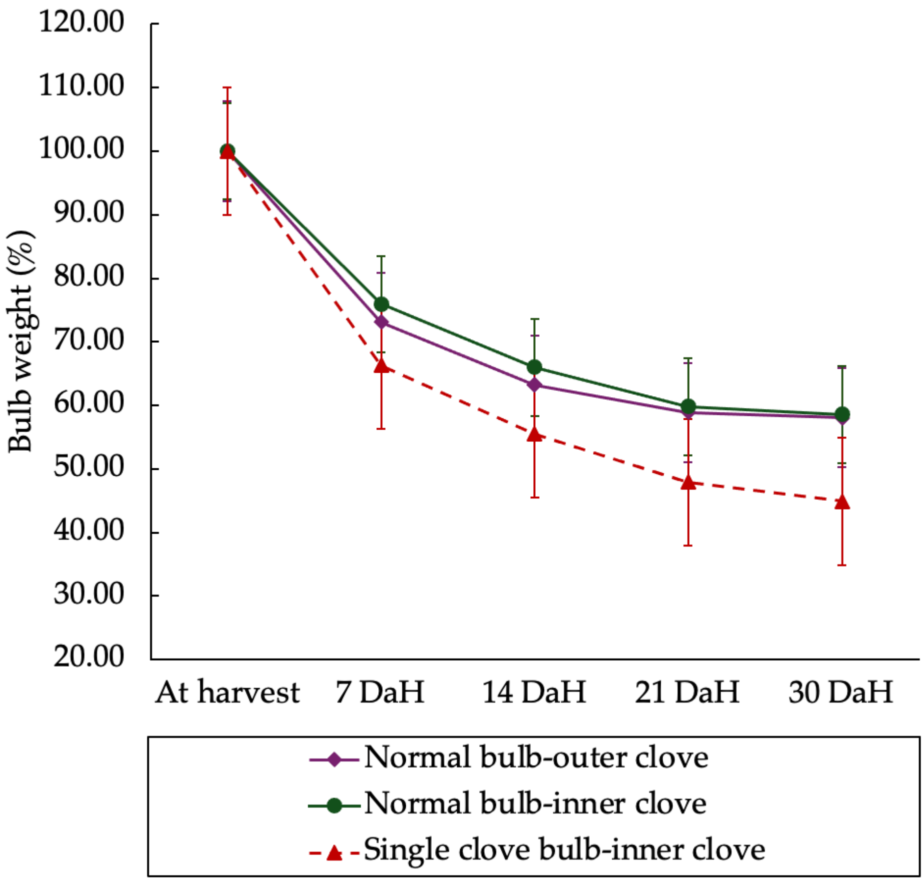

Figure 5. The percentage of bulb weight loss after harvesting and drying *(Day after harvest (DaH))

The fresh produce obtained had bulb diameters ranging from 41.51 to 19.79 mm. Normal bulbs from outer and inner cloves measured 41.51 mm and 38.61 mm in diameter, respectively, with no statistically significant difference. After air-drying for 30 days, normal bulbs from outer and inner cloves measured 39.55 mm and 36.53 mm in diameter, respectively, representing weight loss percentages of 4.70% and 5.36%, with no statistically significant difference (Table 4). Meanwhile, bulbs from inner cloves had a diameter of 19.79 mm at harvest. After drying, single-clove garlic from these bulbs decreased to 17.46 mm in diameter, representing a size reduction of 11.08% (Table 5).

Table 4. Bulb diameters of normal bulb garlic after harvest (-ing) and after 30 days of drying, along with the percentage decrease in bulb diameter during the drying period.

Bulb type	Fresh bulb diameter (mm)	Bulb diameter after 30 days drying (mm)	Percentage decrease in bulb diameters (%)
Normal bulb of outer clove	41.51	39.55	04.70
Normal bulb of inner clove	38.61	36.53	05.36
T-test	ns	ns	ns
CV (%)	28.56	30.15	47.01

Mean within the same column followed by different letters significantly differed between treatments at P≤0.05.
ns = no statistically significant difference

Table 5. Bulb diameters of single-clove garlic after harvest (-ing) and after 30 days of drying, along with the percentage decrease in bulb diameter during the drying period.

Bulb type	Fresh bulb diameter (mm)	Bulb diameter after 30 days drying (mm)	Percentage decrease in bulb diameters (%)
Single clove of outer clove*	—	—	—
Single clove of inner clove	19.79	17.46	11.08

* The data did not detect single-clove garlic from outer clove.
This table presents the average data for single-clove garlic without any statistical analysis.

The neck width of bulbs from mother plants with outer and inner cloves was measured. The neck diameter of fresh bulbs ranged from 7.71 to 4.37 mm. The necks of normal bulbs from outer and inner cloves measured 7.71 mm and 7.33 mm in diameter, respectively, with no statistically significant difference. The bulbs had a neck diameter of 4.37 mm. After air-drying for 30 days, the necks showed shrinkage. The necks of normal bulbs from outer and inner cloves measured 6.90 mm and 6.58 mm, respectively, representing size reductions of 10.62% and 10.53%, with no statistically significant difference (Table 6). Meanwhile, the neck of dried bulbs from inner cloves decreased to 2.45 mm in diameter, representing a size reduction of 42.45% (Table 7).

Table 6. Size of the garlic neck of normal bulbs at harvest (-ing), after curing, and the reduction in neck size.

Bulb type	Neck diameter (mm)		Percentage decrease in neck diameters (%)
	Measured at harvest	After drying for 30 days	
Normal bulb of outer clove	7.71	6.90	10.62
Normal bulb of inner clove	7.33	6.58	10.53
T-test	ns	ns	ns
CV (%)	11.24	13.44	35.80

Mean within the same column followed by different letters significantly differed between treatments at P≤0.05.
ns = no statistically significant difference

Table 7. Size of the garlic neck of single clove at harvest (-ing), after curing, and the reduction in neck size.

Bulb type	Neck diameter (mm)		Percentage decrease in neck diameters (%)
	Measured at harvest	After drying for 30 days	
Single clove of outer clove	—	—	—
Single clove of inner clove	4.37	2.45	42.45

* The data did not detect single-clove garlic.
This table presents the average data for single-clove garlic without any statistical analysis.

The average number of cloves per bulb from normal bulbs obtained from mother plants with outer and inner cloves was 14.77 and 13.01, respectively. The average weight of cloves per bulb was 1.08 g and 1.06 g per clove, respectively, with no statistically significant difference between these values (Table 8).

Table 8. The number of cloves and the weight of cloves per bulb, 30 days after drying.

Bulb type	Number of cloves	Clove weight (g)
Normal bulb of outer clove	14.77	1.09
Normal bulb of inner clove	13.00	1.08
T-test	ns	ns
CV (%)	17.24	16.15

Mean within the same column followed by different letters significantly differed between treatments at P≤0.05.
ns = no statistically significant difference

Comparing the use of outer and inner cloves for cultivation, it was found that bulb size had a strong positive correlation with neck size, yield weight, number of cloves, and clove weight, with correlation coefficients of 0.811, 0.922, 0.799, and 0.644, respectively. Neck size also showed a strong positive correlation with yield weight and number of cloves, with coefficients of 0.794 and 0.848, respectively. Yield weight had a strong positive correlation with the number of cloves and clove weight, with coefficients of 0.829 and 0.707, respectively (Table 9).

Table 9. Correlation between bulb size, neck size, yield weight, number of cloves, and clove weight of garlic grown using different clove positions for planting.

	Bulb size	Neck size	Bulb weight	Clove number	Clove weight
Bulb size	1				
Neck size	.811**	1			
Bulb weight	.922**	.794**	1		
Clove number	.799**	.848**	.829**	1	
Clove weight	.644*	.293	.707*	.256	1

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

3.2 Allicin and antioxidant activity

When considering the types of garlic cloves for bioactive compounds, it was found that single-clove garlic had the highest average amounts of allicin and DPPH inhibition, with 35.79 mg g^{-1} FW and 30.51%, respectively. These values were significantly different from those of normal bulbs obtained from both outer and inner cloves (Table 10).

Table 10. Bioactive compounds, including allicin and DPPH inhibition, in various types of garlic.

Bulb type	Allicin (mg g^{-1} FW)	DPPH inhibition (%)
Single clove	35.79 a	30.51 a
Normal bulb of outer clove	15.71 b	24.30 c
Normal bulb of inner clove	20.60 b	27.86 b
F-test	*	*
CV (%)	38.35	9.97

Mean within the same column followed by different letters significantly differed between treatments at P≤0.05.
* = statistically significant difference (P≤0.05)

4. Discussion

4.1 Mother clove position in garlic seed bulbs on single-clove garlic formation

The results indicated that inner cloves induced single-clove garlic, which is smaller in size and differs in shape from the outer cloves. Qin *et al.* [25] reported that using single-clove garlic as seed is an effective method to achieve higher yields in garlic production, while small cloves can be repurposed to generate single-clove bulbs for future use. Single-clove garlic has only one clove that serves as the storage organ, typically round and smaller than regular garlic. It forms due to incomplete development during the 60-90 days post-planting, influenced by seed quality, environmental conditions, and genetic factors, unlike regular garlic, which forms multiple cloves per bulb [12, 14, 16, 26]. Rungcharoen *et al*. [26] reported that the average fresh weight of normal garlic bulbs was 12,500 kg/ha at 110-120 days for Thai garlic across all production areas in Thailand. The formation of single-clove garlic also reduced yield due to its smaller size and weight compared to normal garlic bulbs [19]. Seed size plays a crucial role in garlic growth and yield, with single-clove seeds providing more nutrients to seedlings. Both garlic plants from single-clove seeds and multi-clove (common) seeds exhibited normal growth and development [25].

Garlic weight loss is attributed to moisture loss, which has been reported to reach 45-50% during the first month post-harvest due to leaf and outer sheath desiccation, and pest damage. Another factor is nutrient availability during cultivation; improper use of chemical fertilizers can lead to reduced garlic weight and faster desiccation during growth and storage, resulting in post-harvest weight and size loss [26-28]. In this experiment, both fertilizer formulas were applied at the same rate, but the application periods differed according to the age of the garlic. However, when calculated, the total nitrogen amount ranged from 40-47 kg/ha, which resulted in a weight loss rate of garlic ranging from 41.47% to 53.73%. Innoi *et al*. [28] reported that applying nitrogen fertilizer at rates of 62.50-193.75 kg/ha in the farmer demonstration area increased leaf number, bulb size, and fresh yield compared to no nitrogen application. However, after one month of drying, the 125.00 kg/ha nitrogen treatment showed a 51.01% weight loss, with 4.73-5.40% clove damage after five months. These findings suggest that the reduction in bulb size during storage correlates with weight loss, which can be used to calculate storage requirements for future sales or planting. Single-clove garlic seeds produced plants with significantly higher fresh and dry mass, larger bulbs, and greater leaf area compared to multi-clove seeds [25].

The trend analysis of garlic bulb weight over time reveals a significant negative linear correlation between the number of days after harvest (DaH) and bulb weight percentage. The trendline equation ($y = -1.4374x + 89.241$), where Y represents the bulb weight percentage and X represents days after harvest, demonstrates a consistent decline in weight. With a coefficient of determination ($R^2 = 0.7372$), the analysis indicates a strong statistical relationship between storage duration and weight loss. The downward slope of the trendline illustrates a substantial and progressive reduction in bulb weight over time, highlighting the critical impact of storage duration on garlic quality and preservation (Figure 6).

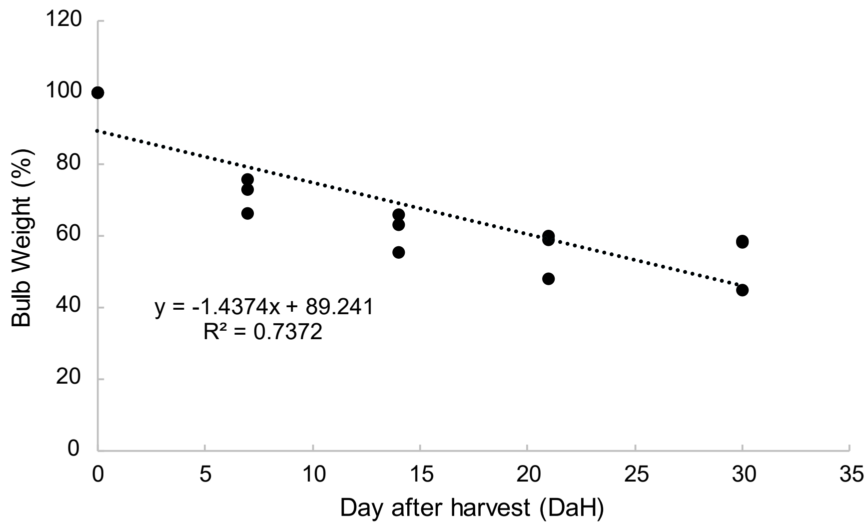

Figure 6. The correlation between storage duration and percentage of bulb weight reveals a consistent weight reduction pattern.

Optimal garlic storage requires careful post-harvest handling to preserve crop quality and longevity. After harvesting, plants should be dried in a shaded, well-ventilated area, maintaining their structural integrity and minimizing disturbance. To prevent disease transmission, avoid washing or cutting the stems and leaves. Once the stems and leaves are thoroughly dried, meticulously sort the garlic by bulb size, removing any shriveled or diseased specimens. Cluster the sorted bulbs and suspend them in a well-ventilated space, protected from direct sunlight, to maximize storage life [14, 16].

Typically, clove size (clove position) ranging from 5.51 to 3.5 grams affects the yield components of garlic bulbs. Larger clove seeds result in higher shoot dry mass, larger neck and bulb diameters, more cloves per bulb, and greater average clove weight [20]. Research by Calimpang *et al*. [29] reveals the nuanced impact of garlic clove size on plant growth, categorizing cloves into four distinct weight ranges: small (1.0-1.49g), medium (1.50-1.99g), large (2.0-2.50g), and extra-large (2.51-3.0g). While larger cloves consistently produce more vigorous plants with higher fresh and dry bulb weights, empirical studies demonstrate no significant variations in yield per plant or hectare across different clove sizes. This counterintuitive finding suggests that although larger cloves enhance specific growth parameters, they do not guarantee proportional yield increases. Complementing these findings, Malashri *et al*. [30] observed that larger cloves generate more extensive leaf development and increased leaf area, thereby improving photosynthetic efficiency and overall plant growth. Their study, conducted using Thai garlic with smaller clove sizes, further underscores the complex relationship between clove size and agricultural performance.

The outer cloves (larger size) and inner cloves (smaller size) did not show significant differences in yield components. This is likely due to cultivation management practices (fertilizer and water supply) and environmental factors. Optimal water and fertilizer management is crucial for improving crop productivity and maintaining the ecological environment, especially under fluctuating climate conditions [31].

Bulb and clove form during the transition of vegetative growth to bulb formation at 60-90 days after planting. Key factors affecting bulb quality and weight during this period include an optimal environment, such as high daytime temperatures and longer daylight hours, the genetic traits, and the variability of garlic [16-17, 32-35].

Another important aspect of bulb growth is the role of leaves in carbohydrate accumulation through photosynthesis, which is crucial for yield and bulb size [17]. The data suggest that early, well-adapted growth leads to prolonged carbohydrate accumulation, resulting in larger bulb size, greater weight, and increased number of cloves.

4.2 Allicin and antioxidant activity

The experimental results indicated that the number of key compounds found in single-clove garlic was higher than in regular garlic. Kunasakdakul *et al*. [36] found that single-clove garlic contains higher levels of key compounds like allicin and alliin compared to regular garlic. The factors influencing garlic composition specifically sulfur-containing volatile compounds, which are responsible for the pungent smell and taste of garlic [37] include geographic, environmental, and climatic differences, variety, storage duration, and dormancy period [6].

Allicin and sulfur compound content in garlic are influenced by physiological processes, variety, and environmental conditions during growth. The nitrogen-sulfur ratio in the growing medium affects the accumulation of sulfur compounds such as alliin, the precursor of allicin, which is related to garlic's flavor and aroma [24, 38-40]. Alliin levels vary within the garlic plant, being lowest in the roots and highest in the buds, indicating that plant physiology and specific functions play roles in alliin accumulation, stored in vacuoles. Leaf damage converts alliin to allicin, reducing alliin levels [3-4]. Alliin levels are the highest in buds and decrease in older leaves after injury, with younger tissues tending to have a higher concentration of alliin.

The formation of cloves in garlic bulbs is influenced by lateral buds in the leaf axils, typically occurring in younger leaves. As the first leaves swell from accumulating food and energy, subsequent leaves form and become the primary storage parts, surrounded by the first leaves [16]. It is possible that inner cloves are younger and, therefore, tend to have higher allicin levels than outer cloves.

4.3 Economic analysis of common garlic and single-clove garlic

The comparative economic analysis of common garlic and single-clove garlic reveals complex market dynamics and production challenges. Common garlic, a staple crop widely cultivated globally, maintains robust market demand but typically yields a lower price per kilogram compared to its specialized counterpart [41, 42]. In contrast, single-clove garlic emerges as a premium product, distinguished by its distinctive characteristics smaller bulbs, nuanced aromatic profile, and exceptional versatility in value-added product development, such as black garlic and artisanal pickled preparations. These unique attributes propel single-clove garlic to command a significantly higher market price, often surpassing common garlic by several multiples, despite demonstrating lower per-unit area yield [43]. However, this economic potential is tempered by substantial production challenges. The cultivation of single-clove garlic involves higher production costs, primarily stemming from the intricate and labor-intensive clove separation process. Furthermore, the limited proportion of plants successfully producing single-clove garlic introduces considerable uncertainty, potentially compromising the economic viability of large-scale commercial production.

The economic landscape surrounding single-clove garlic demands comprehensive research and strategic innovation. Future studies must focus on optimizing production methodologies, reducing operational costs, and enhancing overall efficiency. By systematically addressing these challenges, researchers and agricultural professionals can develop sustainable strategies that maximize the economic potential of single-clove garlic, ultimately creating more attractive opportunities for farmers seeking to diversify their crop portfolios.

5. Conclusions

This study concludes that to increase the proportion of single-clove garlic, inner cloves should be used as the mother plant due to their higher single-clove bulb formation rate than outer cloves. Moreover, the findings from this study suggest that for Thai farmers focused on producing normal garlic bulbs, it is recommended to use outer cloves as the mother plant. This is due to their higher proportion of normal bulb formation and potential for better bulb weight. Alternatively, planting both types together is suggested for easier separation during harvest. Overall, Thai single-clove garlic has higher bioactive compounds and antioxidant capacity compared to normal garlic, supporting the recommendation to consume Thai single-clove garlic to benefit local farmers. Further research and development are needed to enhance the proportion of single-clove garlic to improve production efficiency.

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