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Optimization of crop geometry for improved growth and yield of cabbage varieties under sub-humid conditions

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Abstract

This study is aimed to optimize crop geometry by evaluating key physical and engineering properties of three cabbage varieties (T 621, Golden Acre, and NS 183) under sub-humid conditions to inform tailored planting strategies. Morphological and mechanical traits, including plant height, plant diameter, head dimensions, plant weight, head weight, cutting force, and moisture content, were analyzed using triplicate sampling. Significant varietal differences were observed. NS 183 achieved the greatest height (421.90 mm) and most uniform head weight (C.V. 8.83%), Golden Acre showed exceptional compactness and consistency in plant diameter (C.V. 6.67%), while T 621 exhibited the highest variability across most parameters, particularly in head weight (C.V. 24.75%). These distinct architectural profiles directly influence optimal spatial arrangement. The findings recommend wider spacing for the variable and vigorous T 621 to reduce competition, higher planting density for the compact and uniform Golden Acre to maximize land use, and an intermediate configuration for the tall, consistent NS 183. Implementing these variety-specific geometries is concluded to be a crucial agronomic strategy for enhancing light interception, airflow, and resource efficiency, thereby optimizing growth uniformity and marketable yield in sub-humid production systems.

Keywords: Cabbage, T 621, Golden acre, NS 183, cutting force, coefficient of angle of repose

1. Introduction

Cabbage is a globally significant cole crop, valued for its nutritional density and economic importance in smallholder and commercial farming systems. In sub-humid regions, characterized by moderate rainfall and specific humidity regimes, cabbage production offers a viable source of income and food security. However, yield potential is often sub-optimal due to non-site-specific and non-varietal agronomic practices, particularly plant spacing.

Crop geometry, defined by inter- and intra-row spacing, is a fundamental management lever that dictates plant population, canopy development, and resource capture (light, water, nutrients). An overly dense population induces competition, leading to smaller heads, reduced airflow (increasing disease risk), and lower quality. Conversely, overly wide spacing wastes valuable land, reduces total yield per hectare, and can encourage excessive lateral growth at the expense of head formation (Bracy *et. al* 1993) [2].

While the impact of spacing on cabbage growth is documented, the critical interaction between specific varietal architecture and geometry under sub-humid conditions remains underexplored. Varieties differ markedly in plant frame, leaf orientation, and head size. A 'one-size-fits-all' spacing recommendation fails to account for these genetic differences. This study, therefore, hypothesizes that optimizing crop geometry based on varietal growth habit will significantly improve growth, yield, and yield-contributing parameters of cabbage under sub-humid conditions. The objective was to identify the physical and engineering property of cabbage crop.

2. Materials and Methods

2.1 Experimental site and conditions

The experiment was conducted at Raipur, Chhattisgarh, located in a sub-humid climatic zone. The study area, Raipur, is situated within the Chhattisgarh plains, a sub-humid climatic region classified as a primary rice-growing zone.

This region experiences a mean annual precipitation of 1370 mm, with approximately 85% of the total rainfall concentrated from mid-June through the end of September. Seasonal temperatures exhibit significant variation, with summer maxima peaking at 44.3 °C and winter minima dropping to 12.5 °C. Relative humidity remains elevated from June to October, followed by a steady decline to its lowest annual levels during the peak winter month of January (<https://igkv.ac.in>).

2.2 Observations recorded

The study entailed a comprehensive characterization of selected physical and engineering properties across three distinct cabbage cultivars. The investigated varieties included the hybrids T-621 and NS-183, alongside the open-pollinated standard Golden Acre. Concurrently, critical engineering parameters were measured using standardized instrumental analysis. This systematic recording generated a comparative dataset of the cabbage variety.

2.2.1 Physical property

The various physical properties such as plant height, plant diameter, plant weight, head height, head weight, moisture content, stem diameter (0 cm, 1 cm, and 2 cm from bottom of cabbage head), length of stem for the different Variety T 621, NS 183 and golden acre were measured in the farmer field of Raipur district Chhattisgarh.

2.2.1.1 Plant height

Plant height was measured using a standard measuring tape. For every plant, three individual measurements were taken from the soil surface to the apical meristem (topmost growing point). This triplicate approach ensured accuracy and consistency in the data collection process. The average of these three readings was then computed for each specimen. This resulting mean height served as the definitive measurement for all study-related analysis and comparisons.



Fig 2.1: Measurement of cabbage height

2.2.1.2 Plant diameter

Plant diameter was measured using a standard measuring tape. For each plant, three separate horizontal measurements were taken across the widest span of the outer canopy. This triplicate procedure ensured precision and minimized observational error. The mean of these three values was calculated for every individual plant. This average diameter was then used as the representative data point for subsequent analysis in the study.



Fig 2.2: Measurement of cabbage diameter

2.2.1.3 Plant weight

Plant weight was measured using a calibrated electronic balance. For each harvested plant, three separate weight measurements were recorded to ensure accuracy and account for any minor variability. This triplicate weighing procedure was implemented to enhance data reliability. The mean of these three readings was subsequently calculated for every individual sample. This average fresh weight was then adopted as the definitive value for all further yield analysis and comparative assessment within the research.



Fig 2.3: Measuring cabbage weight

2.2.1.4 Head height

Head height was measured using a flexible measuring tape for overall dimensions and a Vernier caliper for precise, localized depth. Three separate vertical measurements were taken from the base of the head at the stem junction to the apex. This triplicate approach minimized measurement error and ensured consistency. The mean of these three recordings was calculated to establish a representative value for each head. The final averaged measurement, utilizing both tools for comprehensive accuracy, was used for all subsequent morphological analysis.



Fig 2.4: Measurement of head height in lab and field

2.2.1.5 Head diameter

Head diameter was measured using a flexible measuring tape for the maximum outer width and a Vernier caliper for precise core diameter. Three perpendicular measurements were taken across the widest portion of each head to account for asymmetry. This

triplicate method ensured measurement accuracy and consistency. The mean of these three values was calculated to establish a representative diameter for every individual head. The resulting average was then used for comparative analysis of head size and morphology in the study.



Fig 2.5: Measurement of head diameter

2.2.1.6 Head weight

Head weight was determined using a calibrated digital weighing balance. Each harvested cabbage head was weighed three times consecutively to account for any minor instrumental fluctuation. This triplicate measurement protocol was followed to ensure

precision and repeatability of the data. The mean of the three recorded weights was computed for every individual head. This average value served as the final fresh weight datum for all yield and performance evaluations in the study.



Fig 2.6: Measurement of head weight at lab of SV CAET & RS, FAE, IGKV, Raipur, C.G

2.2.1.7 Stem diameter

The stem's thickness was measured at three specific points using vernier calipers: right at the bottom of the cabbage head (0 cm), then 1 cm below it, and again at 2 cm below the base. To make sure every reading was as accurate as possible, each of these three spots was measured three separate times. This careful, repeated

approach helped account for any natural variation or slight human error. The three readings taken at each height were then averaged together, giving one reliable thickness value for the 0 cm, 1 cm, and 2 cm points. These final averaged measurements were used to understand the stem's shape and structure in the study.



Fig 2.7: Measurement of cabbage stem diameter from bottom of cabbage head

2.2.1.8 Stem length

The stem length was determined by measuring the vertical distance from the point of head attachment to the base of the stem using a flexible measuring tape. For precise validation at specific nodes, a Vernier caliper was used to measure localized stem sections. Each measurement was recorded three times to ensure reliability and to average out any minor inconsistencies. The mean of these triplicate observations provided the definitive stem length value. This combined methodological approach ensured both gross dimensional accuracy and localized precision for the study's.



Fig 2.8: Measuring cabbage stem length

2.2.1.9 Moisture content

The moisture content of cabbage stem was determined using the standard gravimetric oven-dry method. Fresh stem samples were precisely weighed and placed in a forced-air oven at 105°C until a constant dry weight was achieved. The dried samples were cooled in a desiccator to prevent moisture reabsorption before final weighing. The moisture content was calculated as the percentage of mass lost relative to the original fresh weight. This procedure was performed in triplicate to ensure analytical accuracy and reliable results.

$$\text{Moisture Content(\%)} = \frac{W_i - W_f}{W_i} \times 100 \quad \dots (3.1)$$

Where,

W_i = Initial weight of sample, g

W_f = Final weight of sample, g

2.2.2 Engineering properties

The two engineering properties such as coefficient of friction angle of cabbage and cutting force of the different Variety T 621, NS 183 and golden acre were measured in the lab of SV CAET & RS, FAE, IGKV Raipur, Chhattisgarh

2.2.2.1 Coefficient of friction angle of cabbage

The coefficient of static friction for cabbage crops is effectively determined using the inclined plane method. In this procedure, a cabbage is placed on a slowly tilting plane and the angle at which sustained sliding initiates is recorded as the angle of friction. To ensure accuracy and account for the vegetable's natural surface variability, this measurement is repeated three times for each individual cabbage, rotating it between trials. The average of these three angles for each cabbage is calculated, and the final coefficient of friction is derived from the tangent of this average angle. This protocol yields a reliable and reproducible value essential for designing post-harvest handling equipment (Sahu *et.al* 2020).

$$B = \sqrt{L^2 + H^2} \quad \dots (3.3)$$

$$F = \tan^{-1} \frac{H}{B} \quad \dots (3.4)$$

Where,

B = Base width of triangle formed, cm

L = Length of MS sheet, cm

H = Vertical height of free end of MS sheet, cm

F = Friction angle, Θ



Fig 2.9: Measurement of coefficient of friction angle of cabbage

2.2.2.2 Cutting force

The required cutting force for the cabbage harvester mechanism was quantified using a texture analyzer fitted with a Warner-Bratzler knife blade. Measurements were taken at stem positions 0, 1, and 2 cm below the head to target the less fibrous zone. Each

clamped stem was cleanly severed at a controlled speed of 10 mm/s to record the peak force. This data directly informs the power specification for the harvester's cutting unit design (Kushwaha *et al.* 1983; Dixit and Rawat, 2022; Liu *et al.* 2025) [10, 5, 12].



Fig 2.10: Measurement of cutting force of cabbage

3. Result and Discussion

The study analyzed the physical and engineering properties of three cabbage varieties T 621, Golden Acre, and NS 183 at

farmer's field of Raipur district Chhattisgarh and engineering properties were tested at the lab of SV CAET&RS, FAE, IGKV, Raipur Chhattisgarh.

3.1 Plant height

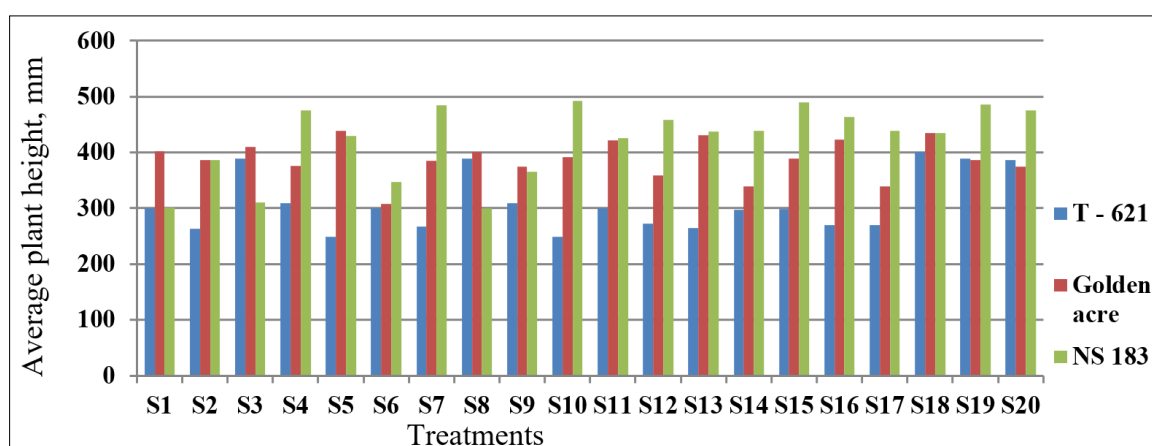


Fig 3.1: Variation of avg. plant height of cabbage variety (T162, Golden acre, NS183)

From the fig 3.1 it was observed that the cabbage variety T 621 yielded an average head height of 308.70 mm. The T 621 cabbage variety exhibited a plant height range from 249.33 mm to 401 mm. The observed standard deviation of 52.119 and coefficient of variation of 16.88% reflect the variability between the sample means, indicating a moderate degree of consistency in the performance of this variety under the trial conditions. The Golden Acre cabbage variety demonstrated a mean plant height of 388.4 mm. The observed heights ranged from a minimum of 307.33 mm

to maximum of 439.00 mm with standard deviation of 34.46 and notably coefficient of variation 8.87%, the data indicates high degree of uniformity in plant stature for this variety under the trial conditions. The cabbage variety NS 183 achieved a mean plant height of 421.90 mm. Individual plant measurements ranged from minimum of 300.33 mm to maximum of 491.67 mm. This was accompanied by a standard deviation of 64.47 and a coefficient of variation of 15.28%, indicating moderate degree of variability in plant height for this particular variety.

3.2 Plant diameter

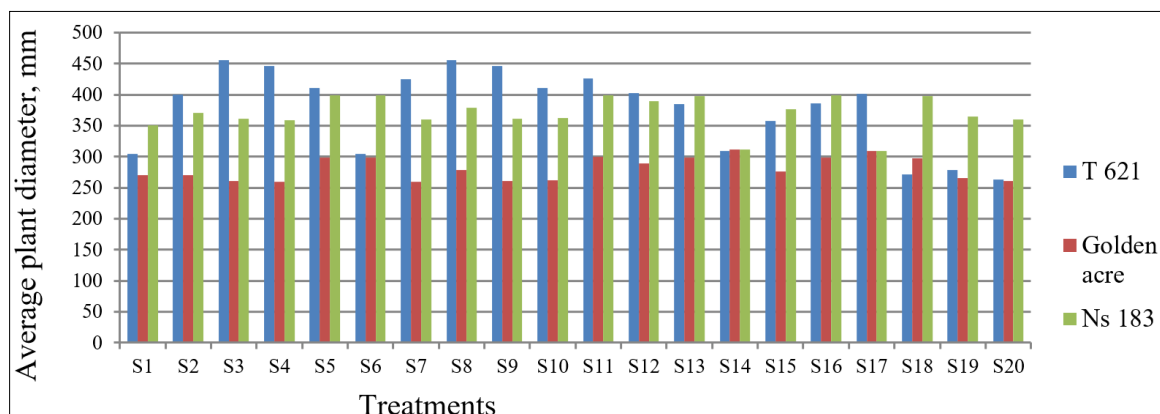


Fig 3.2: Variation of avg. plant diameter of cabbage variety (T 162, Golden acre, NS183)

Based on the average of three replications per sample, the cabbage variety T 621 exhibited a mean plant diameter of 377.20 mm. The average values from each triplicate sample set ranged from 263.67 mm to 456.00 mm. The calculated standard deviation of 64.92 and coefficient of variation of 17.21% reflect moderate level of variability among the sample means for this trait. Based on the average of three replications per sample, the Golden Acre cabbage variety demonstrated mean plant diameter of 281.37 mm. The sample means ranged from 259.33 mm to 312.00 mm. With a standard deviation of 18.78 and a notably low coefficient of

variation of 6.67%, the data indicates a high degree of uniformity and consistency in plant diameter for this variety under the studied conditions. Based on the average of three replications per sample, the NS 183 cabbage variety exhibited a mean plant diameter of 370.36 mm. The triplicate sample means ranged from a minimum of 309.00 mm to a maximum of 399.33 mm. With a standard deviation of 26.63 and coefficient of variation 7.18%, the data indicates a high degree of uniformity and consistent plant diameter for this variety.

3.3 Plant weight

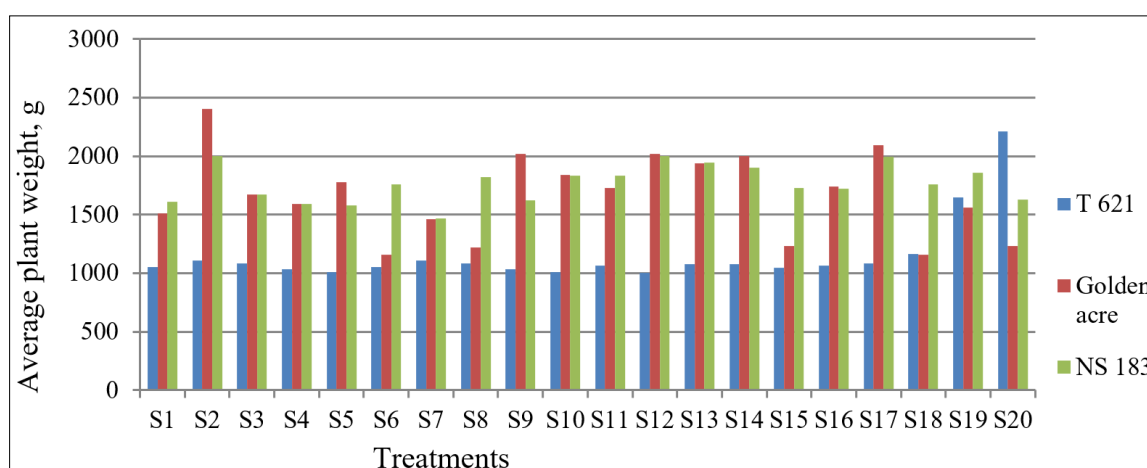


Fig 3.3: Variation of avg. plant weight of cabbage variety (T 162, Golden acre, NS183)

It was clearly observed from fig 3.3, the T 621 cabbage variety yielded a mean plant weight of 1149.77 g. The average minimum weight of cabbage recorded 1005.33 g and maximum average weight of cabbage recorded 2211.00 g. With a standard deviation of 284.54 and a notably high coefficient of variation of 24.75%, the data indicates considerable variability in plant weight among the samples of this variety, despite the averaging of replications. Based on the average of three replications per sample, the Golden Acre cabbage variety produced a mean head weight of 1668.06 g. The average sample weight ranged from minimum of 1159.00 g

to maximum of 2400.67 g. The data, with a standard deviation of 354.69 and a coefficient of variation of 21.26%, indicates a high level of variability in the head weight for this cultivar under the trial conditions.

Data presented on fig 3.3 shows that the NS 183 cabbage variety yielded a mean head weight of 1766.56 g. The avg. of triplicate sample means ranged from 1468.67 g to 2000.67 g. With a standard deviation of 155.93 and a low coefficient of variation of 8.83%, the data indicates a notably high degree of uniformity and consistency in head weight for this variety.

3.4 Head height

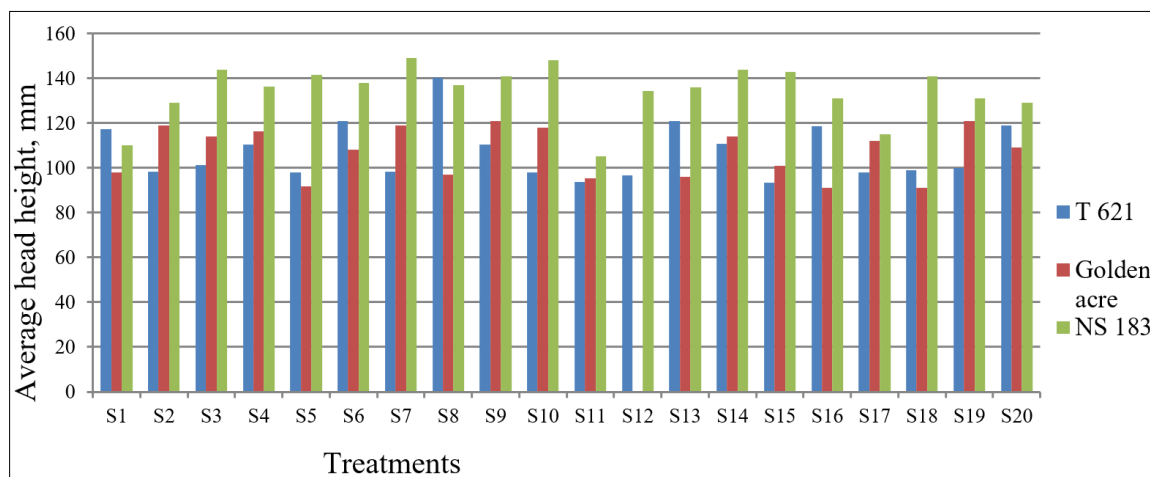


Fig 3.4: Variation of avg. head height of cabbage variety (T 162, Golden acre, NS183)

It revealed from fig 3.4 that the T 621 cabbage variety showed a mean head height of 107.17 mm. The individual sample means ranged from 93.33 mm to 140.33 mm. The calculated standard deviation of 12.42 and coefficient of variation of 11.59% indicate a moderate level of variability in the head height for this cultivar under the evaluated conditions. Based on the average of three replications per sample, the Golden Acre cabbage variety exhibited a mean head height of 106.96 mm. The triplicate sample means ranged from a minimum of 91.00 mm to a maximum of 121.00 mm. With a standard deviation of 11.15 and a coefficient

of variation of 10.42%, the data indicates a moderate to low level of variability in head height, demonstrating reasonable uniformity for this trait in the evaluated cultivar. Based on the average of three replications per sample, the NS183 cabbage variety recorded a mean head height of 129.00 mm. The mean of 20 samples with three replications of each, ranged from 105.33 mm to 149.00 mm. With a standard deviation of 12.29 and a low coefficient of variation 9.16%, the data indicates a high degree of uniformity and consistency in head height for this cultivar.

3.5 Head diameter

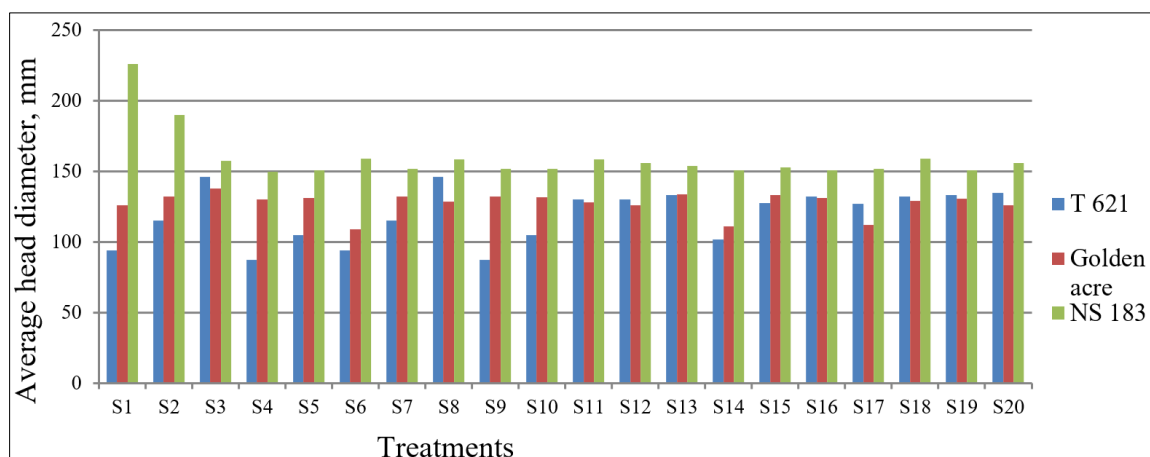


Fig 3.5: Variation of avg. head diameter of cabbage variety (T 162, Golden acre, NS183)

The mean head diameter of the T 162 cabbage variety, calculated from the average of three replications per sample, was 118.8 mm. The observed values spanned from 87.33 mm to 146.00 mm. Statistical analysis revealed a standard deviation of 18.97 and a coefficient of variation of 15.97%, pointing to a fair degree of dispersion in head size among the tested samples of this variety. An analysis of triplicate sample averages for head diameter revealed that the Golden Acre cabbage variety achieved a mean of 127.53 mm, with avg. values of three replication of each sample clustering between 109.00 mm and 137.67 mm. This limited spread is corroborated by a low standard deviation of 7.80 and a coefficient of variation of merely 6.12%, demonstrating remarkable consistency in head size for this cultivar. Statistical evaluation of the NS 183 variety, using averages derived from

three replications per sample, determined the mean cabbage head diameter to be 159.43 mm. Measurements across samples displayed a broad spectrum from 150.00 mm to 226.00 mm. This distribution is characterized by a standard deviation of 17.88 and a moderate coefficient of variation of 11.23%, reflecting a predictable yet notable variation in head diameter for this variety.

3.6 Head weight

The cabbage head weight of T 162 variety, calculated as the average of three replications for each sample, showed considerable variation among the observations. The mean head weight was 625.63 g, indicating a moderate-sized head under the given experimental conditions. The minimum and maximum head weights recorded were 497.00 g and 930.67 g, respectively,

reflecting a wide range in head development. The standard deviation (136.33 g) indicated noticeable variability around the mean, while the coefficient of variation (21.79%) suggested moderate variability in head weight among the samples, which may be attributed to differences in microclimatic conditions, plant vigor, or soil fertility within the experimental farmer field. The cabbage head weight of the Golden Acre variety, calculated as the average of three replications for each sample, exhibited substantial variation among the observations. The mean head weight was 1245.95 g, indicating comparatively heavier heads under the experimental conditions. The minimum and maximum head weights recorded were 849.33 g and 1720.67 g, respectively, showing a wide range in head size. The standard deviation

(282.22 g) reflected considerable dispersion of values around the mean, while the coefficient of variation (22.65%) indicated moderate variability in head weight among the samples, which may be attributed to differences in plant growth, nutrient availability, and field conditions during the cropping period. The cabbage head weight of the NS 183 variety, calculated as the average of three replications for each sample, showed relatively uniform performance. The mean head weight was 1234.95 g, with values ranging from 1040.67 g to 1480.67 g. The standard deviation (129.32 g) indicated low dispersion around the mean. A coefficient of variation of 10.47% reflected good uniformity and stability in head weight among the samples.

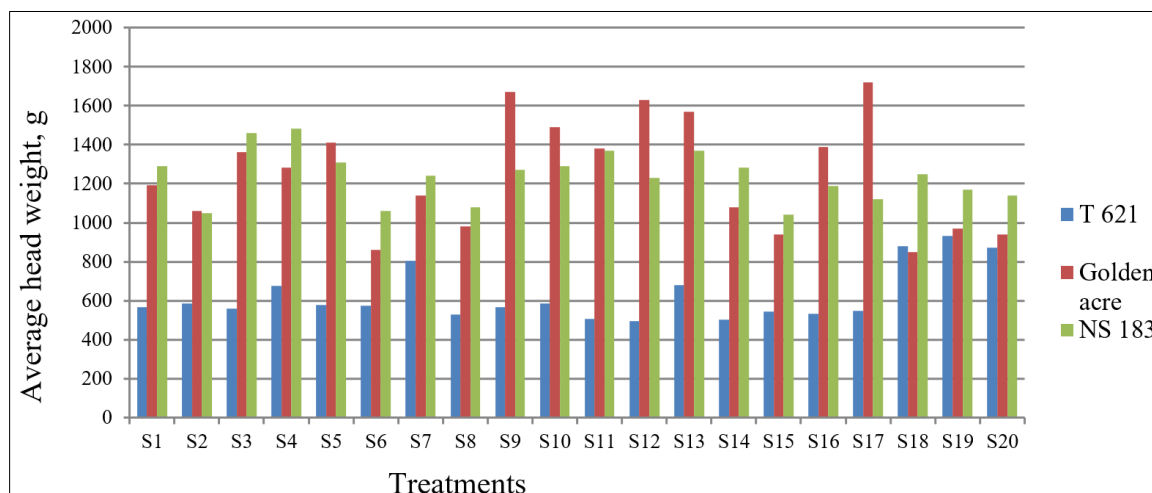


Fig 3.6: Variation of avg. head weight of cabbage variety (T 162, Golden acre, NS183)

3.7 Stem diameter at 0 cm from bottom leaf of cabbage head

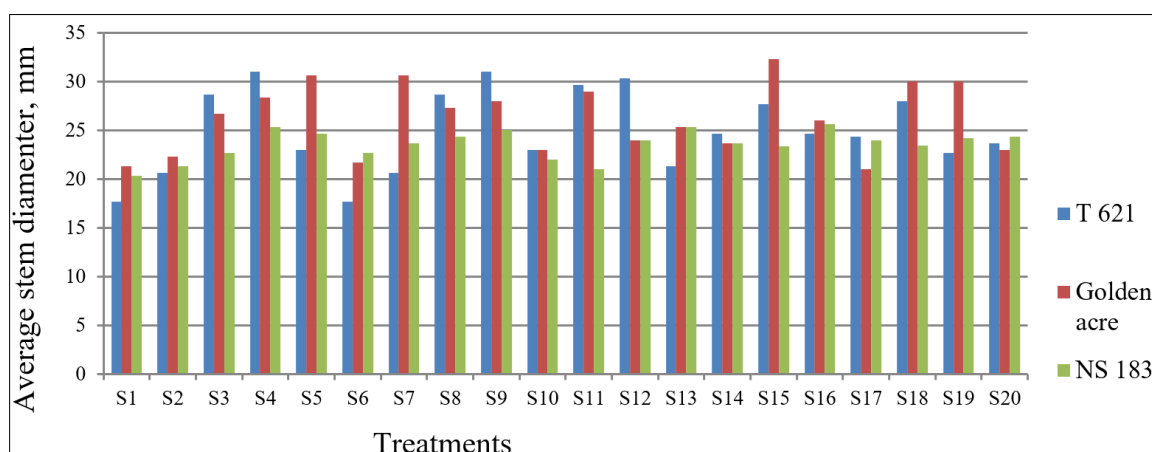


Fig 3.7: Variation of avg. stem diameter at 0 cm from bottom of leaf of cabbage head of cabbage variety(T 162, Golden acre, NS183)

The stem diameter of cabbage measured at 0 cm below the lower leaf of the cabbage head for the T 162 variety, calculated as the average of three replications for each sample, showed moderate variation. The mean stem diameter was 24.95 mm, with a minimum of 17.67 mm and a maximum of 31.00 mm. The standard deviation (4.22 mm) indicated reasonable dispersion around the mean. The coefficient of variation (16.94%) suggested moderate uniformity in stem thickness among the samples. For stem diameter measured immediately below the cabbage head, the Golden Acre variety showed an average of 26.21 mm based on triplicate sampling. The results varied from 21.00 mm to 32.33 mm across the tested samples. This variation is quantified by a

standard deviation of 3.57 and a coefficient of variation of 13.62%, indicating a moderate level of uniformity in stem thickness for this cultivar. The NS 183 variety exhibited a mean stem diameter, measured directly beneath the cabbage head, of 23.54 mm based on averaged triplicate samples. The recorded values fell within a narrow range from 20.33 mm to 25.60 mm. This limited dispersion is reflected in a low standard deviation of 1.48 and a coefficient of variation of 6.29%, signifying a high degree of uniformity in this structural trait for the variety.

3.8 Stem diameter at 1 cm from bottom leaf of cabbage head

For the T 162 variety, the stem diameter measured 1 cm below

the cabbage head averaged 23.28 mm, derived from triplicate sample means. The measurements varied from 17.67 mm to 29.00 mm. This variability is reflected in a standard deviation of 3.75 and a coefficient of variation of 16.11%, indicating a moderate to high degree of dispersion in stem thickness at this specific position for the cultivar. For the Golden Acre variety, the stem diameter measured 1 cm below the cabbage head averaged 25.13 mm based on triplicate sample means. The values ranged from 20.00 mm to 31.33 mm. These results show a standard deviation

of 3.53 and a coefficient of variation of 14.03%, representing a moderate level of variability for this specific stem characteristic in the cultivar. Measured at 1 cm below the cabbage head, the NS 183 variety displayed a stem diameter averaging 22.54 mm when calculated from triplicate sample means. Observations were confined to a narrow span of 19.33 mm to 24.33 mm. This minimal spread is evidenced by a low standard deviation of 1.38 and a coefficient of variation of 6.13%, underscoring the pronounced uniformity in this structural feature for the variety.

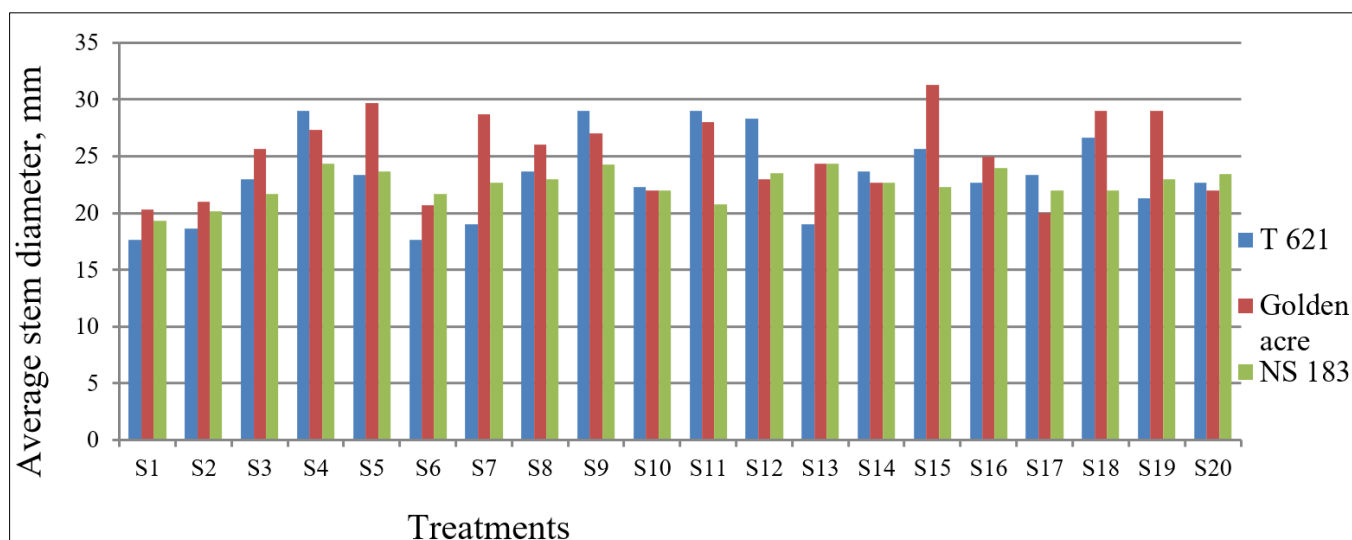


Fig 3.8: Variation of avg. stem diameter at 1 cm from bottom of leaf of cabbage head of cabbage variety (T 162, Golden acre, NS183)

3.9 Stem diameter at 2 cm from bottom leaf of cabbage head

Analysis of the T 162 variety at a point 2 cm below the cabbage head revealed an average stem diameter of 21.5 mm, determined from triplicate sample averages. The data exhibited a range from 15.33 mm to 29.00 mm. With a standard deviation of 3.43 and a coefficient of variation calculated at 15.98%, these results demonstrate a significant degree of variation in stem thickness for this cultivar at the specified measurement point. When measured at a point 2 cm below the cabbage head, the Golden Acre variety yielded an average stem diameter of 24.13 mm from the mean of triplicate samples. The data spanned from 18.33 mm to 30.33 mm.

This distribution is reflected in a standard deviation of 3.69 and a coefficient of variation of 15.28%, which corresponds to a moderate level of variability for the cultivar at this specific stem position. At a measurement depth of 2 cm below the cabbage head, the NS 183 variety maintained an average stem diameter of 21.28 mm, as derived from triplicate sample averages. The results clustered within interval of 18.33 mm to 23.33 mm. This consistency is further demonstrated by a low standard deviation of 1.42 and a coefficient of variation of 6.67%, indicating highly uniform stem dimensions for the variety at this stem section.

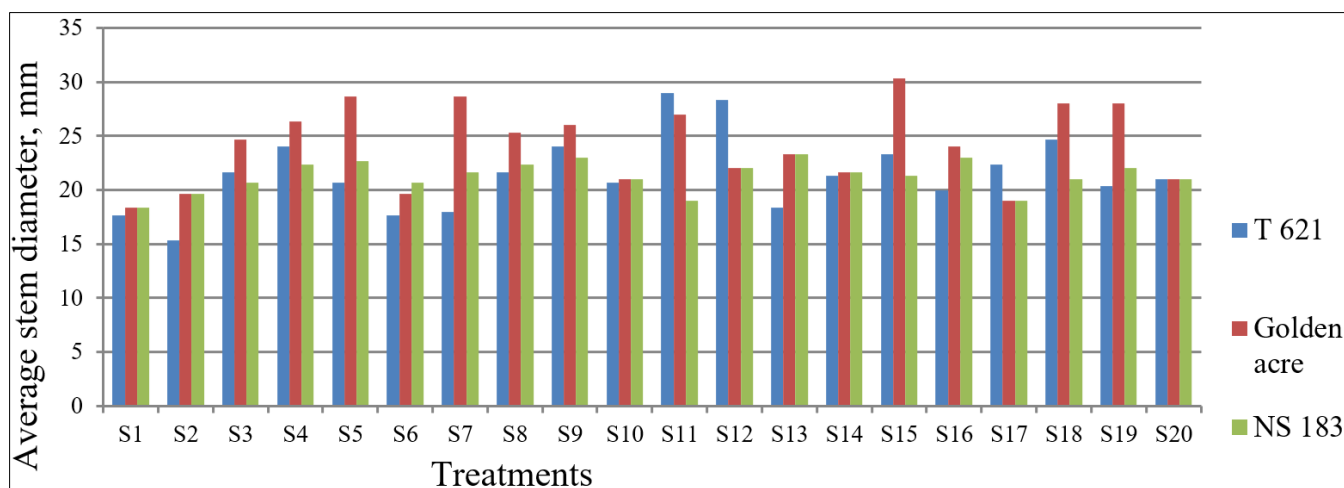


Fig 3.9: Variation of avg. stem diameter at 2 cm from bottom of leaf of cabbage head of cabbage variety (T 162, Golden acre, NS183)

3.10 Moisture content

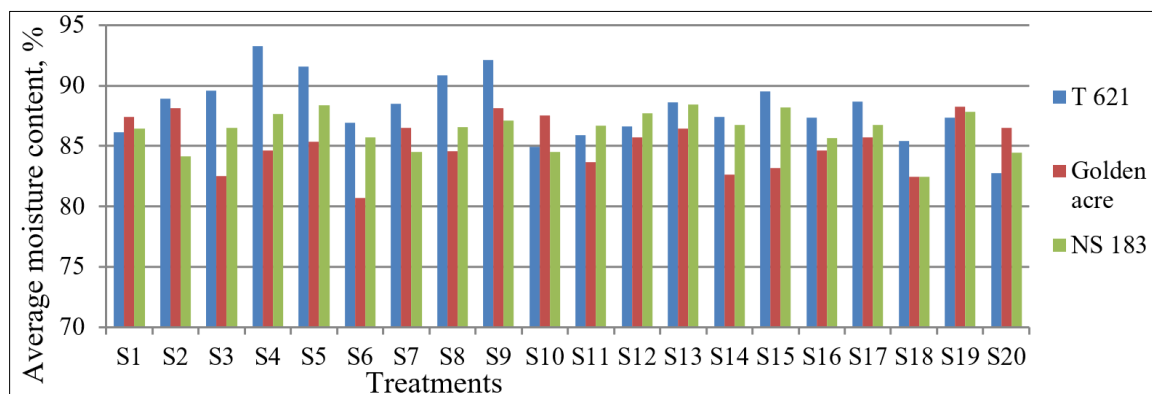


Fig 3.10: Variation of avg. moisture content of cabbage variety (T 162, Golden acre, NS183)

The moisture content of the T 162 cabbage variety averaged 88.14%, based on the mean of triplicate sample analyses. The values were confined to a narrow range of 82.76% to 93.28%. This high consistency is reflected in a low standard deviation of 2.59 and an exceptionally low coefficient of variation of 2.94%, demonstrating remarkable uniformity in water content across the tested samples of this cultivar. The Golden Acre cabbage variety exhibited a mean moisture content of 85.24%, derived from triplicate sample averages. The minimum recorded value was 80.70%, while the maximum reached 88.25%. This notably narrow range between the min and max values is further

evidenced by a low standard deviation of 2.19 and a very low coefficient of variation of 2.57%, collectively confirming exceptional uniformity in moisture retention for this cultivar. The NS 183 cabbage variety displayed an average moisture content of 86.32%, calculated from triplicate sample means. The minimum observed value was 82.48%, and the maximum was 88.45%. This extremely tight distribution is supported by a standard deviation of 1.62 and the lowest coefficient of variation in the study at 1.88%, denoting outstanding homogeneity in water content for this specific genotype.

3.11 Stem length

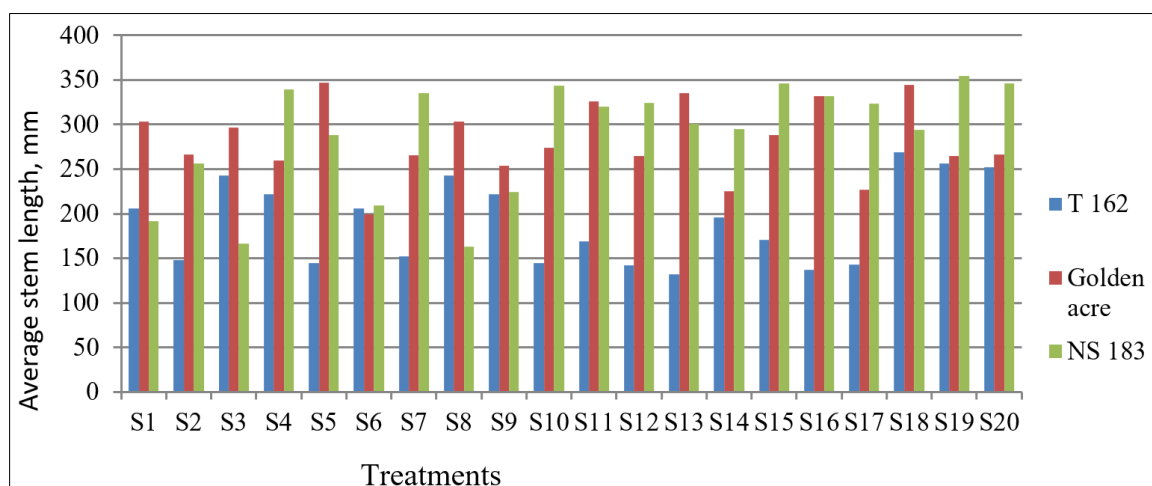


Fig 3.11: Variation of avg. moisture content of cabbage variety (T 162, Golden acre, NS183)

For cabbage variety T 621, the stem length recorded a mean value of 189.9 mm, with minimum of 132 mm and maximum of 269 mm, indicating variation among the samples. The standard deviation of 46.69 mm reflects moderate dispersion of stem length around the mean. The coefficient of variation (24.59%) shows considerable variability, and all observations were calculated from the average of three replications for each sample. For cabbage variety Golden Acre, the mean stem length was 282.07 mm, with values ranging from 199.33 mm to 347.33 mm, indicating variation among the samples. The standard deviation of 41.29 mm shows moderate dispersion of stem length around

the mean. The coefficient of variation (14.64%) indicates relatively uniform stem length, and all data were calculated based on the average of three replications per sample. For cabbage variety NS 183, the mean stem length was 287.72 mm, with a minimum of 163.33 mm and a maximum of 354.67 mm, indicating wide variation among samples. The standard deviation of 63.20 mm reflects considerable dispersion of stem length around the mean. The coefficient of variation (21.97%) suggests moderate variability, and all values were calculated from the average of three replications for each sample.

Engineering properties

3.12 Coefficient of friction angle

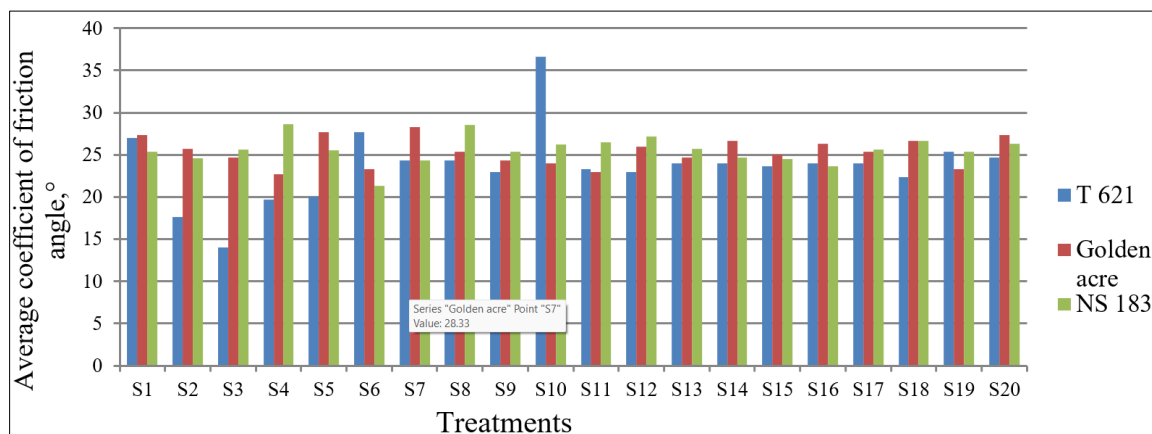


Fig 3.12: Variation of avg. coefficient of friction of cabbage variety (T 162, Golden acre, NS183)

The coefficient of friction angle for the T 162 cabbage variety averaged 23.54° , determined from the mean of triplicate sample measurements. The values ranged narrowly from 20.33° to 25.60° . This low dispersion is indicated by a standard deviation of 1.48 and a coefficient of variation of 6.29%, reflecting highly consistent frictional properties for this cultivar. For the Golden Acre variety, the coefficient of friction angle averaged 25.38° as calculated from triplicate sample means. The results fell within a confined range of 22.67° to 28.33° . This minimal variation is

supported by a low standard deviation of 1.65 and a coefficient of variation of 6.51%, indicating very uniform frictional characteristics for this cabbage cultivar. The NS 183 cabbage variety exhibited a mean coefficient of friction angle of 25.57° derived from triplicate sample averages. Measurements demonstrated a tight range from 25.57° to 28.60° . This high level of consistency is further evidenced by a low standard deviation of 1.62 and a coefficient of variation of 6.32%, reflecting uniform frictional properties in the cultivar's surface characteristics.

3.13 Cutting force

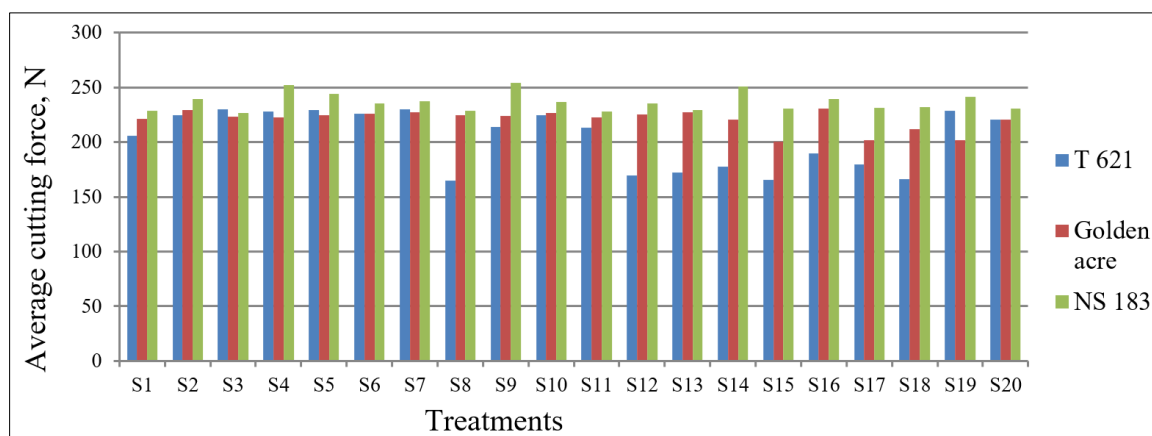


Fig 3.13: Variation of avg. coefficient of friction of cabbage variety (T 162, Golden acre, NS183)

The cutting force measurement for cabbage variety T 162, derived from triplicate sample averages, resulted in a mean of 202.91 N. The obtained values spanned from 164.97 N to 229.67 N. Statistical analysis showed a standard deviation of 26.16 and a coefficient of variation of 12.89%, indicating a moderate level of variability in the force required to cut through stems of this cultivar. For the Golden Acre variety, the cutting force averaged 220.57 N based on triplicate sample means. Measurements clustered between 200.44 N and 230.67 N. This narrow range corresponds to a low standard deviation of 9.24 and a coefficient of variation of just 4.19%, demonstrating highly consistent and uniform cutting resistance in this cultivar. The NS 183 variety required the highest mean cutting force at 236.61 N, calculated from triplicate sample averages. The recorded values exhibited a constrained spread, ranging from 226.73 N to 253.88 N. This limited variability is underscored by a low standard deviation of

8.37 and a remarkably low coefficient of variation of 3.54%, highlighting exceptional uniformity in the mechanical strength and cutting resistance of this cultivar.

Conclusion

The study's findings on varietal physical properties directly inform the optimization of crop geometry for improved cabbage performance in sub-humid climates. The tall but variable stature of T 621 suggests a need for wider spacing to mitigate light competition, while the compact uniformity of Golden Acre allows for higher density planting. NS 183 combination of height and consistent head size indicates it would best utilize an intermediate spacing configuration to maximize yield per unit area. Planting arrangements to these specific architectural traits can optimize light interception, airflow, and resource use. Consequently, implementing variety-specific crop geometries is a key strategy

to enhance both growth uniformity and marketable yield under the specified environmental conditions.

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