



ISAH Indian Journal of Arid Horticulture Year 2023, Volume-5, Issue-1&2 (January - December)

Optimizing Brussels sprout (*Brassica oleracea var. geminifera* L.) yield through strategic sowing dates and environmental parameters across various growth stages

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ARTICLE INFO

Article history:

Received on: 06 December 2024

Accepted on: 06 January 2025

Keywords: Brussels sprout, sowing dates, environment and yield

doi:10.48165/ijah.2023.5.1.6

ABSTRACT

The important exotic vegetable crop in nutritive and cultivation concern had been planted on different dates to study the environmental effect on Brussels sprout growth and yield. The experiment was conducted during 2018 and 2019 at Punjab Agricultural University, Regional Research Station, Gurdaspur. The findings revealed that yield increased significantly with rising maximum, minimum, and mean temperatures. Plant height also showed a positive response to temperature increases. Temperature exhibited a strong and significant correlation with key growth parameters such as the number of leaves, ten-fruit weight, and fruit diameter. Heat use efficiency demonstrated a positive and significant relationship with yield, plant height, number of leaves, ten-fruit weight, and fruit diameter, highlighting its relevance in predicting crop performance. The highest yield was observed when planting done on October 20, while the lowest yield was recorded for the November 10 planting. Similarly, growth attributes, including plant height, number of leaves, ten-fruit weight, and fruit diameter, improved significantly with earlier planting dates. These findings underscore the importance of optimizing planting dates and understanding environmental interactions to maximize Brussels sprout productivity and growth.

Introduction

Brussels sprout (*Brassica oleracea var. gemmifera*) is an important exotic vegetable of brassica family. It is a highly nutritious and known for exceptional nutritive value. Among cole crops, its demand is increasingly day-by-day particularly in metropolitan cities. Brussels sprout is a leading source of protein (4.4% by weight), total carbohydrates (8.9% by weight), and calories (58 per 100 grams) (Brown and Hutchison, 1949). Helm (1963) traced the origin of Brussels sprout to Belgium, suggesting they evolved from the older variety var. *ramose* (thousand head kale) into var. *gemmifera*.

The crop's stem exhibits longitudinal growth, often exceeding one meter in some cultivars. The axillary buds of the petiole leaves develop into miniature heads, just a few centimeters in diameter, which hold commercial value. Early planting has been consistently associated with higher yields (Kriehoff, 1988; Abuzeid and Wilcockson, 1989; Gaye and Maurer, 1991; Babik, 1994).

Keeping in view, the importance of Brussels sprout the present study explores the impact of varying planting dates on the growth and marketable yield of Brussels sprout, with

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particular attention to their correlation with environmental conditions, aiming to provide insights for improved cultivation practices.

Material and Methods

The experiment was carried out during 2018 and 2019 at Punjab Agricultural University-Regional Research Station, Gurdaspur on sandy loam, using Brussels sprout cv. Hills Ideal. In each year the crop was planted at three planting dates with three replications. The experiment was laid out in 2 m x 3 m sized plots. The plot consisting of two rows at a distance of 75 cm x 50 cm from row to row and plant to plant each row consisting 6 plants where total plant per plot was 12. The planting was done on 20th October (D₁), 30th October (D₂) and 10th November (D₃) during 2018 and 2019. The marketable yield (excluding unmarketable buds due to quality defects) of the crop was determined for each planting date at the same time number of days after planting (Table 3) by mechanical harvesting. The date of harvesting coincided with the three to four latest measurements of the total crop. At the same time each observation was also recorded like plant height (cm), number of leaves, weight per plant (g), ten sprout weight (g), fruit length (cm), fruit diameter (cm) to compare the yield quintal per acre with each character. The analysis of variance was carried out with the R statistical package.

Results and Discussion

The yield is a complex polygenic character and the improvement in yield depends on the knowledge and extent of its association with various component characters. An understanding of the association among the different pairs of component characters and their relative association with yield is necessary for improvement in the desired traits. In the present investigation also, the phenotypic correlation coefficients were worked out. The estimates of correlation coefficients among different pairs of characters at phenotypic showed a close resemblance to each other.

Yield demonstrated (Table 1) a positive and significant correlation with maximum temperature during early growth (0.69) and the overall season (0.82), indicating that as temperature increases, both vegetative and reproductive growth improve. However, being a cool-season crop, Brussels sprout exhibited a negative and non-significant correlation with fruiting (-0.44), as temperature had limited influence on this stage. Similarly, yield showed a positive and significant correlation with minimum temperature during early growth (0.88) and the overall season (0.73), but a negative and non-significant relationship with fruiting (-0.32). Mean

temperature displayed the strongest positive and significant correlation with early growth (0.90) and the overall season (0.97), while also having a negative and non-significant relationship with fruiting (-0.40). The intensity, duration, and rate of temperature changes collectively influence plant development and physiology (Wahid *et al.*, 2007).

Yield comparisons with diurnal temperature range revealed a negative and significant relationship with fruiting (-0.49). Evening relative humidity showed a positive but non-significant correlation with fruiting (0.35) and negative correlations with early growth (-0.43) and the overall season (-0.50), the latter being significant. Mean relative humidity exhibited a negative and significant relationship with early growth (-0.59) and the overall season (-0.84), while showing a positive but non-significant correlation with fruiting. Rainfall displayed a negative and non-significant correlation with yield, while bright sunshine hours showed no relation. Wind speed negatively correlated with all growth stages, significantly with fruiting (-0.53). Finally, yield demonstrated a positive response to reference evapotranspiration across all stages, significantly correlating with fruiting (0.73). Most crops experience adverse effects when exposed to high temperatures during the vegetative growth period, a phenomenon well-documented for cool-season annuals such as wheat (Porter and Gawith, 1999) and *Brassica juncea* (Hayat *et al.*, 2009).

Plant height exhibited a significant and positive correlation with yield (0.63). When compared with maximum temperature, plant height showed a positive and significant correlation during early growth (0.51) and the overall season (0.58) but a negative and non-significant correlation with fruiting (-0.37). Similarly, plant height compared with minimum temperature displayed a mix of positive and negative non-significant results. In relation to mean temperature, plant height showed a positive and significant correlation with early growth (0.55) and the overall season (0.53), but a negative and non-significant correlation with fruiting (-0.37). The increase in plant height with rising temperatures highlights the significant influence of temperature on vegetative growth, while its relationship with fruiting remained non-significant. Plant height did not show a significant relationship with the diurnal temperature range. Comparisons with relative humidity in the morning showed a positive but non-significant correlation, while relative humidity in the evening exhibited a negative and significant correlation with plant height during the season (-0.50). Mean relative humidity had a negative and significant correlation with plant height during early growth (-0.51) and the overall season (-0.61), but a positive and non-significant correlation with fruiting (0.33). Rainfall, sunshine hours, wind speed, and evapotranspiration did not significantly affect plant height.

The number of leaves per plant showed a strong positive and significant correlation with yield (0.93). When compared

with maximum temperature, leaves per plant exhibited a positive and significant correlation during early growth (0.68) and the overall season (0.79), but a negative and significant correlation with fruiting (-0.49). Similarly, comparisons with minimum temperature revealed a positive and significant relationship during early growth (0.79) and the overall season (0.64), while the correlation with fruiting was negative and non-significant (-0.35). When compared with mean temperature, leaves per plant displayed a positive and significant correlation during early growth (0.86) and the overall season (0.89), but a negative and non-significant correlation with fruiting (-0.45). Leaves per plant showed no significant correlations when compared with diurnal temperature range, relative humidity (morning, evening, or mean), rainfall, bright sunshine hours, wind speed, or reference evapotranspiration. These factors appeared to have no measurable impact on the number of leaves per plant.

The ten-fruit weight showed a strong positive and significant correlation with yield (0.86). When compared with maximum temperature, ten-fruit weight exhibited a positive and significant relationship during early growth (0.60) and the overall season (0.75), but a negative and non-significant relationship with fruiting (-0.34). Comparisons with minimum temperature revealed a positive and significant correlation with early growth (0.83) and the overall season (0.70), while the correlation with fruiting was negative and non-significant (-0.27). Similarly, ten-fruit weight showed a positive and significant response to mean temperature during early growth (0.82) and the overall season (0.91), but a negative and non-significant relationship with fruiting (-0.32). Factors such as diurnal temperature range, relative humidity (morning, evening, or mean), rainfall, bright sunshine hours, wind speed, and reference evapotranspiration did not have any significant effect on ten-fruit weight.

Fruit diameter showed a significant and positive correlation with yield (0.80), indicating that an increase in fruit diameter is associated with a higher yield. When compared with maximum temperature, fruit diameter exhibited a positive and significant correlation during early growth (0.58) and the overall season (0.69), but a negative and non-significant correlation with fruiting (-0.39). Comparisons with minimum temperature revealed a positive and significant relationship during early growth (0.82) and the overall season (0.67), while the correlation with fruiting was negative and non-significant (-0.29). Similarly, mean temperature showed a positive and significant correlation with fruit diameter during early growth (0.79) and the overall season (0.85), but a negative and non-significant correlation with fruiting (-0.37). Fruit diameter also demonstrated a positive and significant correlation with reference evapotranspiration during early growth (0.30), fruiting (0.77), and the overall season (0.36). Other factors, including diurnal temperature range, relative humidity (morning, evening, or mean), rainfall, bright sunshine hours, and wind speed, did not

show a significant correlation with fruit diameter.

The data presented in Table 2 demonstrate the correlation between Brussels sprout and growing days, as well as thermal growing indices. Yield, when compared with crop stage duration, showed a positive and significant correlation with early growth (0.88), fruiting (0.67), and the entire season (0.93). Yield also exhibited a positive and significant relationship with both growing degree-days and photo-thermal units during early growth (0.97). The yield showed a positive and significant correlation with heliothermal units during early growth (0.69) and the overall season (0.77). Additionally, the photo-thermal index demonstrated a positive and significant correlation with yield during early growth (0.91) and the entire season (0.97). Plant height, compared with crop stage duration, showed a positive and significant correlation with the overall season (0.41), and a positive and significant relationship with growing degree-days during early growth (0.54). Plant height also exhibited a positive and significant correlation with heliothermal units during early growth (0.58) and the entire season (0.62). The photo-thermal index had a positive and significant correlation with plant height during early growth (0.56) and the overall season (0.51). Heat use efficiency showed a positive and significant correlation with yield (1.00), plant height (0.62), number of leaves (0.92), ten-fruit weight (0.86), and fruit diameter (0.82). Crop stage duration was positively and significantly correlated with the number of leaves during early growth (0.80), fruiting (0.56), and the overall season (0.83), as well as with ten-fruit weight during early growth (0.82), fruiting (0.55), and the entire season (0.84), and fruit diameter during early growth (0.78), fruiting (0.81), and the overall season (0.86).

The data presented in Table 3 highlight the significant differences in yield (quintals per acre) across different sowing dates. The maximum yield was recorded in D_1 (61.35), while the minimum yield was observed in D_3 (9.81). D_1 showed no significant difference compared to D_2 , and D_2 was significantly at par with D_3 ; however, D_1 was significantly different from D_3 . The highest recorded yield per acre was 70.2, while the lowest was 7.8. Everaarts and De Moel (1998) also reported that combinations of high plant density and late planting resulted in fewer sprouts per plant.

Table 3 also demonstrates significant differences in plant height (cm) across the three sowing dates. The tallest plants were observed in D_1 (36.4 cm), while the shortest plants were observed in D_2 (14.6 cm). Early planting led to taller plants compared to late planting. Bravo *et al.* (1986) suggested that the period from transplanting to harvest was shorter for later planting dates. The number of leaves per plant showed a significant difference among the sowing dates. The highest number of leaves was observed in D_1 (31.5), while the lowest was in D_3 (20.5). Early sown plants produced more leaves, directly impacting yield. Abuzeid and Wilcockson (1989) noted that early-sown plants produce more buds than late

ones due to a longer growing season.

A significant difference in ten-sprout weight (g) was also observed across sowing dates. The maximum ten-sprout weight was recorded in D₁ (151.83 g), while the minimum was observed in D₃ (75 g), with an overall mean of 111.44 g. Early sowing showed better performance in sprout weight, positively influencing yield, as higher temperatures during early planting promote vegetative growth, while cooler temperatures are essential for bud formation. Vural *et al.*

(2000) also reported that Brussels sprout require a period of low temperatures (12-17°C) for proper bud initiation. The data on sprout diameter (cm) showed significant differences across sowing dates. D₁ (3.28 cm) exhibited the largest sprout diameter, while D₃ (2.11 cm) had the smallest. The overall mean diameter was 2.83 cm. No significant effect on sprout diameter was found between D₁ and D₂, as cooler temperatures are needed for sprout formation, as reported by Grevsen and Olesen (1994).

Table 1. Correlation of yield and related characters of Brussels sprout with growing environ parameters at different growth stages

	Yield	p-Value	Plant height	p-Value	Leaves/plant	p-Value	Ten fruits weight	p-Value	Fruit diameter	p-Value
Yield	1.00	<0.001	0.63	0.005	0.93	<0.001	0.86	<0.001	0.80	<0.001
Maximum Temperature										
Early growth	0.69	0.002	0.51	0.029	0.68	0.002	0.60	0.008	0.58	0.012
Fruiting	-0.44	0.069	-0.37	0.128	-0.49	0.037	-0.34	0.172	-0.39	0.107
Seasonal	0.82	<0.001	0.58	0.011	0.79	<0.001	0.75	<0.001	0.69	0.002
Minimum Temperature										
Early growth	0.88	<0.001	0.36	0.140	0.79	<0.001	0.83	<0.001	0.82	<0.001
Fruiting	-0.32	0.196	-0.35	0.156	-0.35	0.159	-0.27	0.280	-0.29	0.239
Seasonal	0.73	<0.001	0.27	0.288	0.64	0.004	0.70	0.001	0.67	0.002
Mean Temperature										
Early growth	0.90	<0.001	0.55	0.019	0.86	<0.001	0.82	<0.001	0.79	<0.001
Fruiting	-0.40	0.102	-0.37	0.136	-0.45	0.063	-0.32	0.201	-0.37	0.135
Seasonal	0.97	<0.001	0.53	0.025	0.89	<0.001	0.91	<0.001	0.85	<0.001
Diurnal Temperature Range										
Early growth	0.21	0.411	0.33	0.183	0.25	0.311	0.14	0.569	0.13	0.618
Fruiting	-0.49	0.037	-0.31	0.212	-0.56	0.015	-0.36	0.142	-0.43	0.076
Seasonal	0.16	0.534	0.31	0.212	0.20	0.422	0.11	0.657	0.09	0.736
Relative Humidity (Morning)										
Early growth	-0.17	0.501	0.13	0.611	-0.12	0.634	-0.15	0.540	-0.24	0.344
Fruiting	0.18	0.473	0.35	0.156	0.22	0.379	0.12	0.627	0.13	0.610
Seasonal	-0.03	0.903	0.20	0.435	0.02	0.929	-0.06	0.821	-0.07	0.783
Relative Humidity (Evening)										
Early growth	-0.43	0.073	-0.44	0.068	-0.45	0.060	-0.38	0.119	-0.34	0.174
Fruiting	0.35	0.156	0.38	0.117	0.40	0.102	0.26	0.307	0.28	0.263
Seasonal	-0.50	0.035	-0.50	0.037	-0.49	0.040	-0.46	0.055	-0.38	0.116
Relative Humidity (Mean)										
Early growth	-0.59	0.011	-0.51	0.031	-0.58	0.012	-0.53	0.023	-0.46	0.056
Fruiting	0.29	0.248	0.33	0.175	0.34	0.171	0.20	0.421	0.24	0.333
Seasonal	-0.84	<0.001	-0.61	0.008	-0.77	<0.001	-0.81	<0.001	-0.67	0.003
Rainfall										
Early growth	-0.01	0.960	-0.26	0.305	-0.05	0.835	0.01	0.960	0.06	0.813
Fruiting	-0.05	0.845	0.16	0.533	0.01	0.964	-0.09	0.714	-0.09	0.712
Seasonal	-0.32	0.196	-0.09	0.734	-0.25	0.318	-0.38	0.124	-0.26	0.293
Bright Sunshine Hours										

Early growth	0.23	0.363	0.37	0.130	0.27	0.284	0.17	0.501	0.13	0.619
Fruiting	-0.46	0.056	-0.40	0.102	-0.52	0.026	-0.29	0.237	-0.43	0.077
Seasonal	0.18	0.479	0.35	0.160	0.22	0.379	0.15	0.552	0.08	0.763
Wind Speed										
Early growth	-0.15	0.558	-0.33	0.184	-0.20	0.432	-0.10	0.685	-0.03	0.902
Fruiting	-0.53	0.023	-0.05	0.848	-0.41	0.092	-0.49	0.040	-0.50	0.033
Seasonal	-0.40	0.099	-0.41	0.091	-0.42	0.084	-0.38	0.119	-0.23	0.353
Reference Evapotranspiration										
Early growth	0.41	0.088	0.44	0.068	0.43	0.077	0.36	0.142	0.30	0.219
Fruiting	0.73	<0.001	0.42	0.086	0.65	0.003	0.63	0.005	0.77	<0.001
Seasonal	0.46	0.055	0.45	0.063	0.47	0.051	0.40	0.101	0.36	0.14

Correlation values in bold faces are significant at $p \leq 0.05$

Table 2. Correlation of yield and related characters of Brussels sprout with growing days and thermal growing indices

	Yield	p-Value	Plant height	p-Value	Leaves/ plant	p-Value	Ten fruits weight	p-Value	Fruit diameter	p-Value
Crop stage duration days										
Early growth	0.88	<0.001	0.37	0.127	0.80	<0.001	0.82	<0.001	0.78	<0.001
Fruiting	0.67	0.002	0.21	0.402	0.56	0.015	0.55	0.017	0.81	<0.001
Seasonal	0.93	<0.001	0.41	0.091	0.83	<0.001	0.84	<0.001	0.86	<0.001
Growing Degree Days (GDD)										
Early growth	0.97	<0.001	0.54	0.022	0.91	<0.001	0.89	<0.001	0.85	<0.001
Fruiting	-0.14	0.579	-0.30	0.226	-0.25	0.325	-0.10	0.693	-0.03	0.910
Seasonal	0.96	<0.001	0.49	0.041	0.88	<0.001	0.89	<0.001	0.86	<0.001
Photo-thermal unit (PTU)										
Early growth	0.97	<0.001	0.54	0.021	0.91	<0.001	0.89	<0.001	0.85	<0.001
Fruiting	-0.20	0.432	-0.32	0.191	-0.30	0.233	-0.15	0.543	-0.09	0.735
Seasonal	0.96	<0.001	0.48	0.042	0.88	<0.001	0.89	<0.001	0.85	<0.001
Helio-thermal unit (HTU)										
Early growth	0.69	0.001	0.58	0.011	0.68	0.002	0.62	0.007	0.53	0.025
Fruiting	-0.27	0.280	-0.33	0.183	-0.36	0.146	-0.16	0.517	-0.20	0.421
Seasonal	0.77	<0.001	0.62	0.006	0.74	<0.001	0.71	0.001	0.58	0.011
Photo-thermal index (PTI)										
Early growth	0.91	<0.001	0.56	0.016	0.86	<0.001	0.82	<0.001	0.79	<0.001
Fruiting	-0.35	0.157	-0.33	0.179	-0.41	0.093	-0.26	0.293	-0.31	0.213
Seasonal	0.97	<0.001	0.51	0.032	0.89	<0.001	0.91	<0.001	0.86	<0.001
Heat use efficiency (HTU)										
Seasonal	1.00	<0.001	0.62	0.006	0.92	<0.001	0.86	<0.001	0.82	<0.001

Correlation values in bold faces are significant at $p \leq 0.05$

Table 3. Analysis of variance

Planting Date	Yield (q/ ha)			Plant height (cm)			Leaves/ plant (no.)			Ten fruits weight (g)			Sprout diameter (cm)		
	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.
D ₁ (20 th Oct.)	61.35± 7.62a	52.2	70.2	30.77± 6.81a	20.9	36.4	31.5± 2.16a	29	35	151.83± 18.65a	125	175	3.28± 0.23a	3.0	3.6
D ₂ (30 th Oct.)	31.80± 2.26b	28.3	34.2	22.10± 3.86b	14.6	25.4	24.66± 1.86b	22	27	107.50± 10.35b	90	120	3.11± 0.27a	2.8	3.6
D ₃ (10 th Nov.)	9.81± 1.43c	7.8	11.3	23.36± 3.15b	20.2	28.9	20.50± 2.25c	18	24	75.00± 18.43c	50	105	2.11± 0.19c	1.8	2.3
LSD	5.74			5.64			2.58			20.04			0.29		
Grand Mean	34.32			25.40			25.55			111.44			2.83		

Conclusion

This study reveals the intricate dynamics shaping the growth and yield of Brussels sprout in response to environmental conditions and sowing dates. The crop's yield displayed a positive correlation with maximum, minimum, and mean temperatures, demonstrating its sensitivity to temperature variations. Vegetative growth parameters such as plant height increased with rising temperatures, further highlighting temperature's role in development. Key growth attributes, including the number of leaves, ten-fruit weight, and fruit diameter, were positively influenced by temperature, reinforcing the importance of environmental factors in the plant's development. Heat use efficiency, a critical metric for evaluating plant performance, significantly correlated with traits like yield and growth parameters, validating its utility in assessing productivity.

Sowing dates emerged as a pivotal factor, with the highest yield recorded for planting on October 20. Early sowing improved critical growth characteristics, such as plant height, leaf count, fruit weight, and diameter, emphasizing the importance of optimal planting times for achieving maximum productivity. This research underscores the potential of Brussels sprout as a high-value crop with remarkable nutritional benefits. Understanding the interplay of environmental factors and cultivation practices enables growers to optimize yields, enhance nutritional value, and contribute to sustainable agricultural practices, paving the way for further advancements in this versatile crop.

Acknowledgments

Authors wish to express their sincere thanks to Director, PAU-Regional Research Station, Gurdaspur for his valuable guidance and providing the required facilities to carry out this investigation.

Conflict of Interest

The authors have no conflict of interest.

Data Sharing

All relevant data are within the manuscript.

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