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Original Article

Evaluation of Parthenocarpic Cucumbers in Passive Greenhouse Under Organic Production System in Indian Cold Desert Ladakh

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Abstract

Protected cultivation has emerged as a transformative solution for vegetable production in cold-arid regions, like Ladakh, India, where open-field agriculture is severely constrained by sub-zero winter temperatures, intense radiation, limited water, and a short growing season. Cucumber (*Cucumis sativus* L.), especially gynoecious and parthenocarpic hybrids, offers tremendous potential under passive solar and polycrbonate greenhouse conditions due to its seedless fruit set without pollination and superior market demand. However, localized evaluation of hybrids is crucial before commercial adoption due to genotype-environment interactions affecting yield and quality. The present study was conducted during summer 2021 at the Precision Farming Development Centre, Stakna, Ladakh to evaluate five parthenocarpic cucumber hybrids - Aviva, Koyal, Jointer, Albela, and Sania - under passive greenhouse conditions. The experiment followed a Randomized Block Design with four replications. Standard organic cultivation practices were adopted, with drip irrigation and vermicompost as nutrient sources. Observations were recorded on vegetative, yield, and quality traits. Data were analyzed using analysis of variance, correlation, and path analysis through OPSTAT. Results revealed significant genotypic variability among the hybrids. Koyal emerged as the most promising hybrid, recording the highest yield, number of fruits per plant, and number of harvests, reflecting superior productivity and sustained fruiting. Sania exhibited the longest vine length and harvest duration and the highest flesh-to-seed cavity ratio, indicating superior fruit quality. Aviva showed favorable total soluble solids and larger fruit circumference, making it desirable for premium markets. Correlation analysis identified yield per hectare as being most strongly associated with fruits per plant and number of harvests, while path analysis revealed fruits per plant as the most influential direct determinant of yield. Traits such as vine length and harvest duration contributed substantial indirect effects. Overall, the study demonstrates that parthenocarpic cucumber hybrids perform exceptionally well under Ladakh's passive greenhouse system, with Koyal being the most suitable hybrid for early summer cultivation due to its high yield potential, prolonged harvest period, and adaptability. The findings highlight the importance of genotype-specific selection for optimizing productivity and profitability of greenhouse cucumber cultivation in cold desert environments.

Categories: Field & Horticultural crops sustainable production, Sustainable climate smart agriculture

Keywords: parthenocarpic cucumber, greenhouse cultivation, cold desert, yield, fruit quality, genotype evaluation, ladakh

Introduction

Ladakh, the cold desert of India, faces severe challenges in agriculture: harsh winters (down to −30°C), intense UV radiations, short growing season, and scarce water resources [1]. Greenhouses such as passive solar, trench, low tunnels, and polyhouses-have revolutionized farming here by creating controlled and favorable microclimates. In Ladakh,

greenhouse cultivation, although practiced for decades, has witnessed accelerated adoption in recent years due to its efficacy in mitigating the adverse effects of climatic aberrations that compromise the viability of open-field vegetable production. In addition, it provides favorable micro-climate to the plants for optimal growth and production that enables to extend growing season in both the directions of normal growing period [2]. Furthermore, even under normal growing season, vegetables grown under greenhouse are superior in yield and quality as compared to those grown under open-field conditions [3]. Passive solar and polycarbonate greenhouses elevated internal temperatures by 7-8°C, aiding winter vegetable growth [1]. Trench greenhouses (6 × 4 × 2 ft to larger versions) retained substantial warmth with yields significantly above open-field norms [4]. Chinese-style polyhouses (100 × 20 ft) are effective during winter for various cool season crops and potentially suitable for cucurbits during summers, although detailed cucumber-specific data are limited [5]. Moreover, low-quality planting material still poses a challenge to productivity even in protected structures [4].

Cucumber, particularly the smooth-skinned, seedless varieties, enjoys year-round demand due to its popularity in salads, sandwiches, and other dishes [6]. In fact, gynoecious and parthencarpic cucumber hybrids have revolutionized greenhouse industry throughout the world. However, the popularity of each hybrid has its own specificity depending on adaptability to particular growing conditions, such as stability regarding pistillate flowering [7] and local market demands for specialized fruits. The precocity or earliness for fruit bearing and harvest is the desired characters for early summer production that fetches high price. Additionally, the cultivar may have high yield potential and good commercial quality that relates to consumers preference. Since a huge investment is involved in greenhouse production system, farmers of this region cannot afford wrong selection of cultivars, especially of very costly gynoecious and parthenocarpic cucumber hybrids [2]. Parthenocarpy refers to the development of seedless fruits without fertilization of ovules. In cucumbers, this trait eliminates the need for pollinators and is especially useful in protected environments like greenhouses where pollination is restricted. Advantages of parthenocarpic cucumber cultivation include reliable fruit set without insects, extended fruiting periods, uniform fruit quality-ideal traits for greenhouse production [8].

Research gap in cold desert Ladakh includes lack of greenhouse specific genotypes and cultivation of monoecious cucumber in greenhouses causing late harvest and low yield per unit area. While specific research on gynoecious and parthenocarpic cucumber performance in Ladakh is lacking, informed extrapolations are possible. In arid regions such as Rajasthan, parthenocarpic cucumbers under insect-proof net houses have performed well. Hybrids like Ruchi-707 produced vine yields of 3.74 kg per vine and 11.57 tons per 500 m^2, with excellent economic returns [9]. Studies on gynoecious/ parthenocarpic hybrids in arid western India identified Ekron (5.3 kg per plant) and Terminator (4.2 kg) as top yielders in early summer greenhouse production; Terminator also offered favorable earliness and quality [2].

Given Ladakh's growing greenhouse adoption, parthenocarpic cucumbers could thrive by avoiding dependence on pollinators in enclosed systems, taking advantage of trench and solar greenhouses for season extension, and producing high per-plant yields despite the region's logistical constraints, similar to those in arid plains. The cucumber yield under protective cultivation can be increased manifold as compared to than in open field cultivation. The productivity of cucumber inside polyhouses was more than four times as compared to open field cultivation [10]. Therefore, prior to the commercial adoption of any gynoecious cucumber hybrid, it is essential to evaluate its production potential under local agro-ecological conditions, with emphasis on vegetative growth, earliness, yield, and fruit quality. Commercial quality, which encompasses physical attributes such as fruit color, shape, size, texture, and shelf life, plays a critical role in determining consumer acceptability in local markets [11]. An ideal cultivar should thus strike a balance between high fresh yield and desirable market traits to ensure both consumer satisfaction and economic returns for farmers. Cultivar selection should be guided by key parameters including earliness, plant vigor, fruit yield, quality, and local market preferences [12]. Given the unique characteristics of Ladakh's passive greenhouse systems - where internal microclimate is closely influenced by ambient conditions - site-specific cultivar evaluation becomes a prerequisite. In this context, the present study was undertaken to address the research gap and to identify a suitable cucumber hybrid for early summer cultivation with good yield potential in Ladakh, based on comprehensive assessment of vegetative and reproductive performance along with key commercial quality attributes under protected greenhouse conditions in the cold desert environment of India.

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Materials And Methods

Experimental site

The field experiment was conducted under protected environment condition of greenhouse at the Experiment Field of Precision Farming Development Centre, Stakna during the summer 2021. The site is located at an altitude of approximately 3,319 m above mean sea level and experiences a cold-arid climate, characterized by low precipitation, high solar radiation, and large diurnal temperature variations.

Weather parameter

The chart (Figure *1*) highlights monthly variation in temperature and humidity, showing how the weather conditions changed throughout the experimental period. The maximum temperature (blue bars) gradually increases from 10.21°C in March to a peak of 26.43°C in July, then slightly decreases to 15.19°C in October. The minimum temperature (orange bars) starts very low (−5.46°C in March), rises to a maximum of 10.92°C in July, and decreases again towards October (−1.56°C). This indicates a clear warming trend from March to July followed by cooling from August to October. Humidity is highest during the warmest months (July and August) and lower during cooler months (March-May). Though the parameters are for open field conditions but there is nearly +10°C temperature (maximum as well as minimum) and +12% humidity in passive greenhouse.

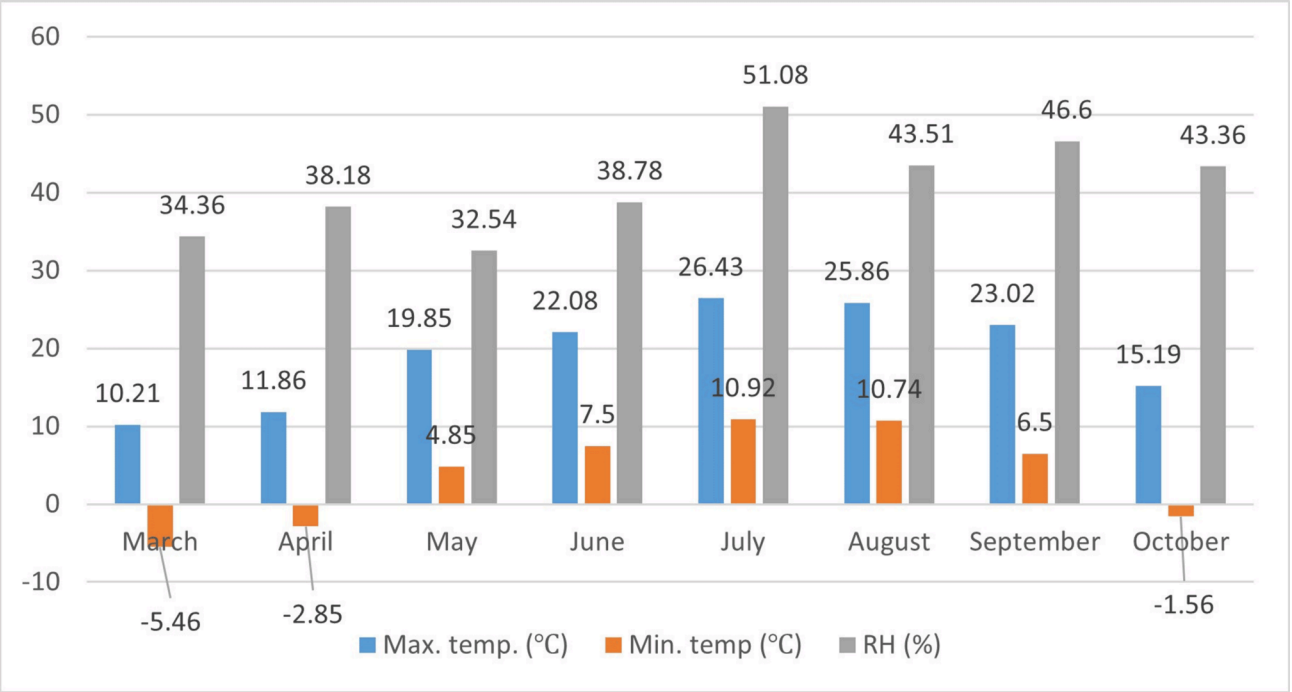


FIGURE 1: Weather parameter of the experimental area during the period of study.

Greenhouse structure specifications

Experiment was carried out in passive greenhouse model known as LREDA greenhouse promoted by Ladakh Renewal Energy Development Agency, Leh. The greenhouse has overall dimensions of 50 feet in length and 18 feet in width, with its longitudinal axis-oriented East-West. The northern wall (back wall) and both side walls are constructed using mud bricks, finished with mud plaster, providing thermal mass for passive temperature regulation. The southern face of the greenhouse, which receives maximum solar radiation, is clad with a 150-micron Rigidex polyethylene (PE) sheet. This material is chosen for its high light transmittance, UV resistance, and mechanical durability, contributing to an optimized

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internal microclimate suitable for year-round cultivation. The roof spans 3 feet in width and is constructed using a framework of angle iron sections, into which willow sticks are inter-filled to serve as the primary roofing material. This assembly is supported by vertical iron poles, ensuring adequate structural strength and resistance to environmental loads such as wind or snow. The design provides both stability and ventilation potential, depending on implementation.

Experimental design

The experiment was laid out in a Randomized Block Design (RBD) with five parthenocarpic cucumber hybrids and four replications.

Treatment details

Following gynoecious and parthenocarpic hybrids were taken for evaluation:

1. Aviva (Brand Indosem, Tropica Seeds, Bengaluru, India)

2. Koyal (Amazon Seeds, Solan, India)

3. Jointer (Amazon Seeds, Solan, India)

4. Albela (Amazon Seeds, Solan, India)

5. Sania (Known-You Seeds (India) Pvt. Ltd., Pune, India)

Spacing and sowing

Spacing was kept 70 × 70 cm (row-to-row × plant-to-plant). Pit of 1 × 1 ft is made. Seed of cucumber were sown at a depth of 2-3 cm on March 9, 2021. Each treatment plot consisted of 12 plants per replication, arranged to maintain uniform plant density.

Cultural practices

Organic agronomic practices for cucumber cultivation under protected conditions were followed uniformly across all plots. Vermicompost 50 g/pit was applied prior to seed sowing and subsequently at 18-20 days intervals. Drip irrigation was used to maintain optimum soil moisture. No chemical fertilizer application was done. Training and pruning were done periodically.

Data collection

Observations were recorded on the following parameters from eight randomly selected plants in each plot.

Vine length (VL; cm): It was recorded at the final stage of picking and measured from the soil level to the longest tip of the plant.

Number of fruits per plant: Total weight of fruits picked at each harvest were taken into consideration to work out number of fruits per plant.

Yield per hectare (YPH; Q): Total weight of fruits harvested from the plants in one square meter area was taken and extrapolated to yield per hectare.

Number of harvest (NOH): The total number of pickings per plant was recorded and the mean value was computed to estimate the average number of harvests per plant.

Days to first harvest (DFH): Total number of days from sowing of seed to first marketable fruit harvest were counted and mean was taken.

Harvest duration (HD): Total number of days from first fruit picking to final fruit picking were counted as HD.

Fruit weight (FW; g): The selected fruits (eight number) per plant were weighed and average FW was recorded.

Fruit length (FL; cm): The polar length of same selected fruits was recorded with measuring scale, and average FW was recorded.

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Fruit circumference (FC; mm): After recording fruit weight and fruit length, same fruits were used for recording the circumference with the help of Digital Calipers (Make- Mitutoyo; Model 500-196).

Flesh-to-seed cavity ratio (FCR): Fruits were cut lengthwise to measure the length of seed cavity and flesh. The ratio of flesh-to-seed cavity was worked out and mean values were taken.

Total soluble solids (TSS; ^{O}B): With the help of a digital hand-held refractometer (Make-Atago; Model-Pal-1), the TSS content of the fruits was recorded and mean value was calculated.

Statistical analysis

The recorded data were subjected to Analysis of Variance (ANOVA) as per the procedure for RBD using OPSTAT. Correlation coefficients and path analysis was also worked out using OPSTAT. Treatment means were compared using the least significant difference (LSD) at 5% level of significance.

Results And Discussion

Overall, the yield and quality of vegetable production in different growing media under protective structures have shown a huge improvement which is not possible under open-field conditions [13]. Naturally ventilated polyhouse was found to be more efficient protected structure for producing high yields and good-quality greenhouse cucumber fruits [14]. Results obtained are presented in Tables *1* and 2 and discussed character-wise.

Vine length

VL (cm) is a vital morphological trait in cucumbers, especially under greenhouse cultivation, where controlled environmental conditions can amplify genetic differences among hybrids. In the present study, a statistical comparison of five cucumber hybrids grown under passive greenhouse (Table *1*) revealed two distinct groups based on VL. Aviva, Koyal, and Sania were categorized under group "A," showing no significant difference among them, while Jointer and Albela, classified under group "B," also did not differ significantly from each other. Among all treatments, Sania recorded the highest mean VL (220.0 cm), indicating superior vegetative vigor in the controlled environment of the greenhouse. This enhanced growth could be attributed to the hybrid's inherent genetic potential, which is often more fully expressed in optimized conditions such as regulated temperature, humidity, and light availability. On the other hand, Albela exhibited the lowest VL (178.0 cm), suggesting either a genetically more compact growth habit or lower responsiveness to the passive greenhouse environment in cold deserts. These findings are consistent with the earlier results [15,16] stating significant genotypic variability in cucumber plant height under protected cultivation. According to their studies, the greenhouse environment not only supports greater vertical growth due to extended internode elongation and optimized CO_2 levels but also enhances expression of vigor-related traits in high-performing hybrids.

Furthermore, taller plant architecture under greenhouse conditions can be beneficial for vertical trellising systems, commonly used to maximize space utilization and light interception [17]. However, excessively tall plants may increase labor requirements for training and pruning, and in some cases, may lead to reduced stability if not supported adequately. Therefore, while Sania may be preferred in greenhouse systems focused on high vegetative growth and potential yield, shorter hybrids like Albela could be suitable where compact plant architecture and ease of management are priorities

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Number of fruits per plant

Hybrids	Vine length (cm)	Number of fruits per plant	Yield per ha (Q)	Number of harvest	Days to first harvest	Harvest duration (days)
Aviva	218.025[a]	23.860[c]	1428.274[b]	34.750[a]	107.000[a]	104.000[a]
Koyal	216.750[a]	29.960[a]	2065.179[a]	35.000[a]	107.000[a]	104.000[a]
Jointer	183.000[b]	21.170[d]	1093.274[c]	32.250[b]	103.000[b]	89.000[b]
Albela	178.000[b]	19.050[e]	978.452[c]	32.000[b]	106.000[a]	86.000[c]
Sania	220.000[a]	25.110[b]	1596.429[b]	34.750[a]	106.500[a]	104.500[a]
CD (5%)	6.622	1.224	118.485	0.645	1.052	1.052

TABLE 1: Performance of parthenocarpic cucumber in passive greenhouse for vine characters.

Superscript in the table followed by the same letter (a, b, c, e, …, z) indicates non-significant values from one another at significant level P<0.05 according to least significant test (LSD).

The number of FPP is one of the most critical yield - contributing traits in cucumber, especially in greenhouse cultivation systems where controlled conditions often enhance flowering, fruit set, and overall productivity. In the present study, significant variability was observed among the five evaluated cucumber hybrids (Table *1*). Each hybrid occupied a distinct statistical group, indicating the difference in fruit-bearing capacity under greenhouse conditions.

The hybrid Koyal recorded the highest mean number of fruits per plant (29.96), demonstrating its superior performance in the protected environment. This could be attributed to its enhanced reproductive efficiency and better fruit-setting ability in the absence of abiotic stress, which is typical in greenhouses. On the other hand, Albela, with the lowest mean (19.05 fruits/plant), showed the least responsiveness to passive greenhouse conditions for this trait. The statistical uniqueness of all five hybrids-Sania (Group B), Aviva (Group C), Jointer (Group D), Albela (Group E), and Koyal (Group A-top performer) highlights the genotypic variability in their reproductive potential. Such variability is common among cucumber hybrids grown under greenhouse conditions [16,17] where microclimatic factors like optimal temperature, humidity, and CO_2 levels can enhance or suppress genetic expression of fruiting traits.

Moreover, greenhouse environments facilitate better pollination control, regulated nutrient application, and disease management, which collectively contribute to improved fruit set in well-adapted hybrids [18]. In particular, hybrids like Koyal and Sania, which performed well, may possess enhanced floral traits, efficient nutrient partitioning, or better compatibility with pollination strategies, making them more suitable for high-density or vertical farming systems. Conversely, lower fruit numbers in hybrids such as Albela could result from poor flower-to-fruit conversion, fewer female flowers, or suboptimal physiological adaptation to greenhouse conditions. Not all hybrids perform well in protected environments, emphasizing the need for environment-specific hybrid development [19]. The clear genetic differentiation observed in FPP among these cucumber hybrids reinforces the importance of selecting hybrids, specifically bred for greenhouse performance, where maximizing the number of marketable fruits is often a key goal for commercial growers.

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Yield per hectare

YPH is the most decisive parameter for evaluating the economic performance of cucumber hybrids, particularly in greenhouse cultivation, where yield optimization is a primary objective. The current study revealed statistically significant variation in yield performance among the five cucumber hybrids (Table *1*) under greenhouse conditions, indicating substantial genotypic differences in yield potential.

Among the evaluated hybrids, Koyal recorded the highest mean yield of 2065.179 quintals per hectare, clearly outperforming all other hybrids. This exceptional performance may be attributed to its superior traits such as higher fruit count, greater fruit weight, and longer harvest duration-all of which contribute positively to total marketable yield. The controlled environment of the greenhouse marked by optimal temperature, humidity, and absence of biotic and abiotic stresses allows such high-performing hybrids to express their full yield potential [16,17]. On the contrary, Albela showed the lowest mean yield (978.452 Q/ha) and, along with Jointer, was grouped under group "C," indicating no significant difference between these two hybrids but a clear inferiority compared to others. The lower yield in Albela may be a result of its reduced number of fruits per plant, smaller fruit size, and shorter harvest duration, as indicated by associated traits in this study. This aligns with earlier findings [15], who reported that yield in cucumbers under greenhouse conditions is highly influenced by both fruit set and the length of the harvesting period. Interestingly, Sania emerged as statistically unique (Group A) with a distinct yield performance, despite not being the top yielder. This suggests that while Sania may not have the highest absolute yield, its yield level is significantly different from most other hybrids, possibly due to consistent performance across multiple yield-contributing traits such as plant height and harvest duration. Similarly, Aviva, placed in group "B," also showed a distinct yield behavior, suggesting that it possesses a moderate but consistent yield potential under greenhouse conditions. The significant differences observed among the hybrids underline the importance of selecting genotypes specifically adapted to protected cultivation. Hybrids bred or evaluated under open-field conditions may not necessarily perform similarly under greenhouse environments due to differences in light intensity, humidity, CO_2 concentration, and nutrient dynamics [18]. Thus, Koyal stands out as the most promising hybrid for greenhouse production in terms of total yield, while Sania and Aviva also exhibit stable and significant performance, making them suitable for commercial cultivation depending on specific production goals and market demands.

Number of harvests

The NOH is an important indicator of the productive duration and continuity of fruiting in cucumber cultivation. In greenhouse production systems, where environmental conditions are optimized, NOH reflects a hybrid's ability to sustain fruiting over time, which directly influences total yield and labor scheduling.

In the present study, cucumber hybrids Aviva, Koyal, and Sania showed no significant differences in number of harvests (Table *1*) and were grouped under Group "A," indicating a comparable and prolonged harvest window. In contrast, Jointer and Albela, grouped under Group "B," had significantly fewer harvests, suggesting a shorter productive lifespan under greenhouse conditions. Among all treatments, Koyal stood out with the highest mean number of harvests (35.0), while Albela had the lowest mean (32.0). Though the numerical difference may appear modest, in high-value greenhouse systems, each additional harvest can represent a notable increase in marketable yield and profitability [15]. The superior performance of Koyal could be attributed to better plant vigor, sustained flowering, and fruit set, as well as resistance to physiological stresses that may emerge over time, even under protected environments.

Greenhouses provide a controlled and extended growing season, allowing certain genotypes to express longer fruiting cycles without being constrained by harsh weather or pest pressures. Cucumber hybrids with longer productive periods are particularly suited for vertical trellising systems and staggered harvest markets, where consistent supply is crucial [16]. Sania and Aviva, which also performed well in terms of NOH, show potential for such systems. On the other hand, hybrids like Albela and Jointer, which showed a shorter harvest duration, might be more appropriate for short-cycle production systems or regions with limited greenhouse availability, but may fall short in maximizing yield potential. Hybrids vary significantly in their harvest span due to differences in reproductive longevity and response to controlled environments [18].

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Thus, Koyal's ability to maintain more harvests position it as a strong candidate for high-frequency harvest strategies in commercial greenhouse cucumber production, whereas Albela's shorter productive phase may limit its suitability in such systems unless paired with specific management interventions.

Days to first harvest

DFH is an essential indicator of earliness in cucumber, directly affecting market timing and profitability, especially in protected cultivation where early yield can command premium prices. In this study, Aviva, Koyal, Albela, and Sania were statistically similar (group "A") for DFH, showing no significant differences among them (Table *1*), while Jointer, which belonged to group "B," exhibited earliness by reaching first harvest in 103.0 days - the lowest among all treatments. In contrast, Aviva took the longest time (107.0 days), indicating slight delayed maturity.

The observed earliness in Jointer under greenhouse conditions may be attributed to its genetic makeup allowing faster flower initiation and fruit development. Earliness is often enhanced under greenhouses due to optimal temperature, humidity, and CO_2 levels, which support rapid vegetative and reproductive development [17]. However, genotypic responsiveness to these conditions remains a critical determinant. Early harvest is particularly advantageous in high-input systems like greenhouses, where maximizing the return on investment per day is essential. Hybrids like Jointer may therefore be suited for short duration or staggered production cycles, while late-maturing ones like Aviva might fit better in systems prioritizing yield over time [16]. Gynoecious and parthenocarpic hybrids are known for early maturity. But in this case, they took more than 3 months for first harvest owing to low temperature conditions unconducive for early growth thereby delaying the maturity.

Harvest duration

HD refers to the span between first and last harvests, reflecting a hybrid's productive longevity and sustained fruiting capacity. In this study, Aviva, Koyal, and Sania exhibited similar HDs and were statistically grouped together (Group "A"). However, Jointer and Albela emerged as statistically distinct, forming groups "B" and "C," respectively (Table *1*).

Sania stood out with the longest HD (104.5 days), suggesting prolonged fruiting, which is desirable for steady market supply and higher cumulative yields. On the other hand, Jointer, despite being the earliest to harvest, showed the shortest harvest duration (86.0 days), implying a more concentrated harvest period.

In greenhouses, longer HD is beneficial when labor, infrastructure, and markets allow sustained picking. Hybrids with extended harvesting periods under greenhouse conditions can utilize the full potential of protected structures, especially in off-season production [15]. However, shorter-duration hybrids may be more efficient in multi-cycle or rotational cropping systems, providing faster turnover.

Fruit weight

FW significantly influences market preference, yield, and profitability. In the present analysis, the cucumber hybrid Koyal recorded the highest fruit weight (314.245 g), while Albela had the lowest (233.645 g). Statistically, Aviva and Koyal were similar (Group "A"), Aviva and Sania were also similar (Group "B"), and Jointer, Albela, and Sania fell into Group "C," reflecting overlapping performance across groups (Table *2*).

The superior performance of Koyal may be attributed to its efficient source-to-sink nutrient allocation, improved fruit set, and better fruit development under greenhouse microclimate conditions. Greenhouse conditions favour larger fruit size due to steady nutrient and water availability and reduced stress. This makes Koyal particularly suitable for fresh market sales where size and uniformity are valued. In contrast, hybrids like Albela, with smaller fruits, may be suitable for pickle or processing industries, or markets where smaller fruits are preferred. The expression of fruit weight under greenhouse is highly genotype-specific and responsive to controlled fertigation and pruning strategies.

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Hybrids	Fruit weight (g)	Fruit length (cm)	Fruit circumference (mm)	Flesh to seed cavity ratio	TSS (°B)
Aviva	304.595^{ab}	21.350^{a}	46.210^{a}	0.258^{a}	4.575^{a}
Koyal	314.245^{a}	21.792^{a}	46.000^{a}	0.252^{a}	2.800^{b}
Jointer	245.845^{c}	19.710^{a}	42.985^{b}	0.255^{a}	1.450^{e}
Albela	233.645^{c}	19.678^{a}	42.842^{b}	0.190^{b}	1.850^{c}
Sania	266.750^{bc}	21.988^{a}	44.310^{ab}	0.272^{a}	1.800^{d}
CD (5%)	40.754	NS	2.657	0.186	0.028

TABLE 2: Performance of parthenocarpic cucumber in passive greenhouse for fruit characters.

Superscript in the table followed by the same letter (a, b, c, e, …, z) indicates non-significant values from one another at significant level P<0.05 according to least significant test (LSD). NS, Not Significant

Fruit length

FL is a key trait in cucumbers, directly influencing market preferences, especially in fresh markets where uniformity and size are crucial for consumer appeal. In this study, all hybrids were statistically non-significant for FL (Table *2*), suggesting non-significant genetic differences for this trait under greenhouse conditions. However, Sania recorded the highest mean FL (21.988 cm), while Albela had the lowest (19.678 cm).

The relatively uniform performance across genotypes may be a result of the stable microenvironment in greenhouses, which minimizes abiotic stress and allows consistent expression of morphological traits like fruit elongation [16]. Despite non-significant differences, the higher FL in Sania suggests its potential in premium markets where long, slender cucumbers are preferred. FL in cucumber is influenced by both genotype and growth environment, and while field conditions may induce variability, greenhouses ensure uniform growth, reducing inter-genotypic variation unless the genetic base is wide [17]. Sania, showing both good length and other favorable traits, could thus be a strong candidate for commercial greenhouse cultivation.

Fruit circumference

FC is another important market trait, affecting not only consumer preference but also fruit firmness and shelf life. In the current study, Aviva, Koyal, and Sania formed Group "A" with statistically similar and non-significant mean FC (Table *2*), while Jointer, Albela, and Sania also grouped together in Group "B," showing overlap.

Aviva exhibited the highest mean FC (46.21 mm), while Albela had the lowest (42.842 mm), indicating some variation despite the general statistical similarity. Larger fruit circumference is generally desirable for bulk markets and processing, as it allows more biomass per fruit and better handling characteristics [19]. Greenhouse conditions typically enhance both length and girth due to regulated moisture, temperature, and nutrient uptake. However, the relatively narrow

variation in fruit circumference across hybrids suggests that genetic factors play a more dominant role here than environmental conditions alone [15]. Hybrids like Aviva, combining greater circumference with early yield traits, could be valuable in both retail and institutional supply chains.

Flesh-to-seed cavity ratio

The FCR is a crucial quality trait, especially for fresh-cut, salad, and export markets, where consumers prefer fruits with more edible flesh and fewer seeds. In the present study it is observed that Aviva, Koyal, Jointer, and Sania fell under Group "A," indicating non-significant differences (Table *2*); Albela was the only member of Group "B," and also had the lowest FCR (0.19); and Sania recorded the highest FCR (0.272), indicating more flesh and smaller seed cavity.

A higher FCR is a desirable trait and strongly associated with better texture and eating quality [19]. The performance of Sania suggests a genetic advantage for high-quality fruit structure, making it suitable for retail packaging and premium segments. Greenhouse-grown cucumbers tend to have thicker flesh walls due to uniform water uptake and lower stress, but genotype still plays a dominant role in determining FCR [16]. Albela's lower FCR might reflect poor adaptability to protected cultivation in terms of internal fruit quality, despite acceptable yield traits.

Total soluble solids

TSS are a major indicator of fruit sweetness and flavor quality, which are increasingly important in consumer-driven cucumber markets. In this study, Koyal was the only hybrid in Group "B," showing a significantly distinct and high TSS; Albela and Sania were grouped in Group "C & D" (moderate TSS); Jointer stood alone in Group "E," with the lowest mean TSS (1.45°B); and Aviva recorded the highest mean TSS (4.575°B) among all treatments (Table *2*).

High TSS is desirable for fresh consumption, and the performance of Aviva and Koyal suggests superior sugar accumulation and carbohydrate metabolism, possibly linked to efficient photosynthate translocation due to high CO_2 under greenhouse conditions [20]. On the other hand, the low TSS in Jointer may reduce its desirability in taste-sensitive markets. TSS in cucumber is not just genotype-dependent but also influenced by light intensity and CO_2 enrichment, which are often optimized in greenhouses [17,18]. This implies that high-TSS hybrids may be particularly responsive to advanced climate control technologies.

Correlation matrix

Correlation analysis among the agronomic and quality traits in cucumber was done to elaborate the interrelationships among the studied variables (Figure *2*).

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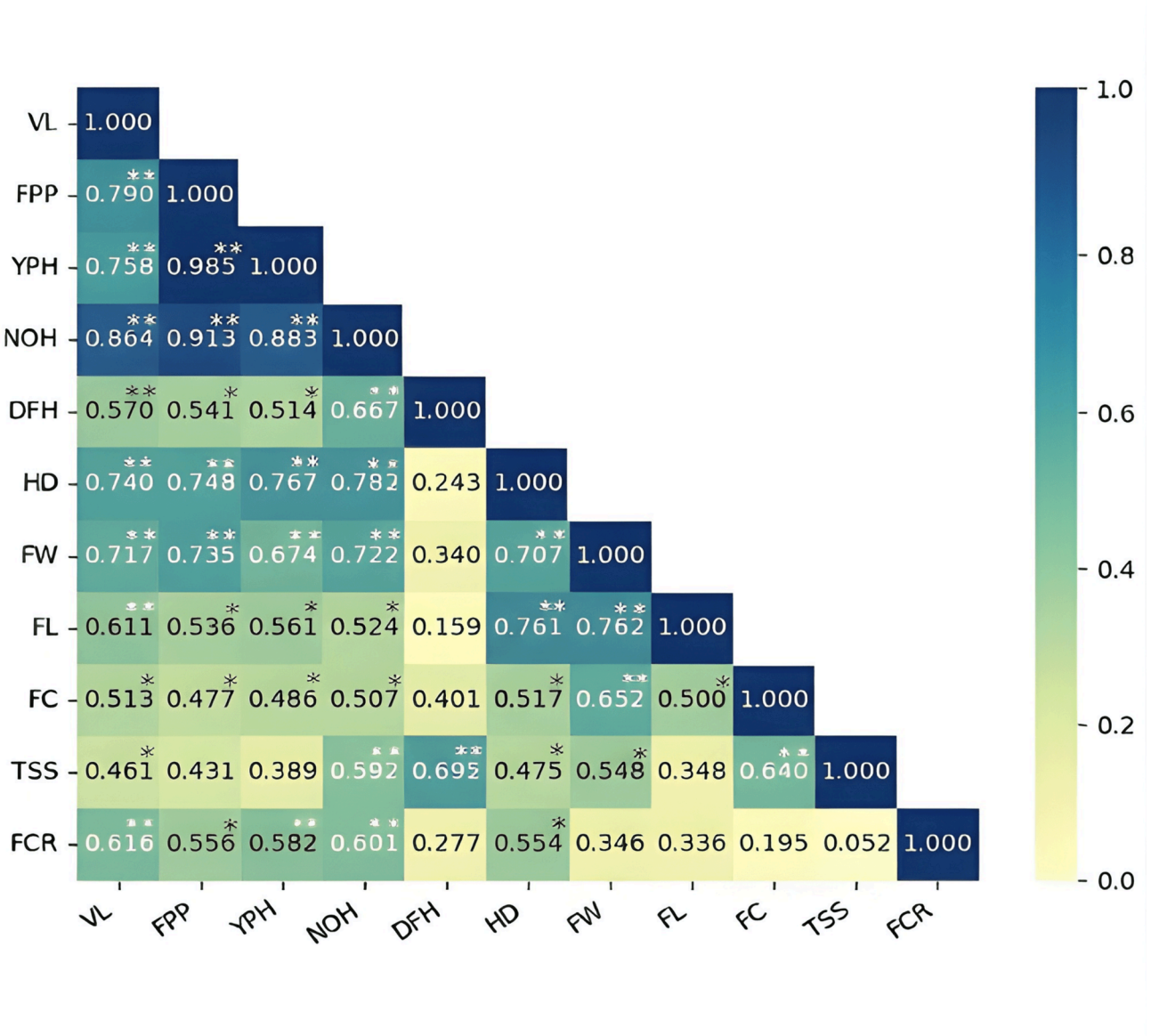


FIGURE 2: Correlation heat map.

*Significant at 5% level of significance; ** Significant at 1% level of significance.
VL, Vine Length; FPP, Fruit per Plant; YPH, Yield per Hectare; NOH, Number of Harvests; DFH, Days to First Harvest; HD, Harvest Duration; FW, Fruit Weight; FL, Fruit Length; FC, Fruit Circumference; TSS, Total Soluble Solids; FCR, Flesh-to-Seed Cavity Ratio

YPH shows the highest positive correlation (r = 0.985) with FPP, suggesting that FPP is a major determinant of yield in cucumber. This strong association aligns with earlier findings [21,22], where fruit number was directly linked to increased yield. YPH also has significant correlations with other variables such as NOH, HD, VL, FW, FCR, FL, DFH, and FC, indicating that a multitude of vegetative and reproductive traits jointly contribute to yield performance [22]. A study found significant positive correlations found between yield per plant and traits such as VL, number of FPP, FL, fruit diameter, and FW [23]. Notably, YPH is not significantly correlated with TSS, which implies that yield improvement might not impact the fruit's sugar content or quality traits. In another study, cucumber yield was positively correlated with FW, FL, and plant height [24,25].

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VL has the highest positive correlation ($r = 0.864$) with NOH, indicating that longer vines may support prolonged or more frequent harvesting. It also significantly correlates with FPP, YPH, HD, FW, FCR, FL, DFH, FC and TSS, highlighting its central role in both vegetative vigor and fruit productivity. Earlier study also recorded significantly positive association of VL with fruit length, fruits per plant and yield [2,25]. However, VL shows non-significant correlations with other unspecified traits, possibly reflecting redundancy or lack of dependence among certain physiological parameters. This supports the fact emphasizing VL as a growth-related yield component. Correlation of FPP is strongest with YPH ($r = 0.985$), confirming its direct contribution to yield [22, 25]. Significant correlations with NOH, VL, HD, FW, FCR, DFH, FL, and FC [22] further underline its importance in breeding programs. Similar to YPH, FPP shows non-significant correlations with TSS, suggesting a trade-off or independence between productivity and sugar content.

NOH shows the highest correlation with FPP ($r = 0.913$) and significant associations with almost all other variables viz. FPP, YPH, VL, HD, FW, DFH, FCR, TSS, FL, and FC. This wide range of positive relationships indicates that frequent harvests are an integrative outcome of favorable growth and reproductive traits. However, NOH also has non-significant correlations with unspecified traits, suggesting selectivity in its influence. DFH had highest correlation ($r = 0.695$) with TSS [22], signifying a linkage between earlier harvest and potentially better sugar accumulation. DFH also correlates significantly with TSS, NOH, VL, FPP, and YPH, supporting the idea that earlier fruiting may lead to higher productivity [22]. It is non-significantly correlated with HD, FW, FL, FC, and FCR, implying timing of first harvest does not always influence size-related traits or harvest span. HD exhibits its highest correlation ($r = 0.783$) with NOH, confirming that longer harvest windows naturally facilitate more harvesting events. HD also has significant correlations with NOH, YPH, FL, FPP, VL, FW, FCR, FC, and TSS, linking it to both yield and quality traits. However, its non-significant correlation with DFH suggests that early harvest initiation does not necessarily extend the harvest period.

FW has the highest positive correlation ($r = 0.762$) with FL, highlighting the tight linkage between fruit size attributes. It significantly correlates with FL, FPP, NOH, VL, HD, YPH, FC, and TSS, suggesting its value in both productivity and quality determination [22,25]. FW shows non-significant correlations with DFH and FCR, suggesting that fruit weight is more related to growth than timing or ratio traits. FL correlates most strongly ($r = 0.762$) with FW, confirming a direct relationship between length and weight. It is significantly associated with FW, HD, VL, YPH, FPP, NOH, and FC, indicating its integral role in marketable fruit characteristics. However, FL has non-significant correlations with DFH, TSS, and FCR, suggesting it is less influenced by early development or quality traits like sweetness. FC has the strongest positive correlation ($r = 0.652$) with FW [22,25], reinforcing that both size traits are interlinked. It also correlates significantly with FW, TSS, HD, VL, NOH, FL, YPH, and FPP, suggesting its potential as a selection criterion. Non-significant correlations with DFH and FCR imply limited relationship with early maturity or efficiency traits.

FCR correlates most with VL ($r = 0.616$) and significantly with VL, NOH, YPH, FPP, and HD, implying its relevance in evaluating productivity efficiency. Non-significant correlations with DFH, FW, FL, FC, and TSS suggest it may not capture quality or early yield aspects effectively. TSS shows that the highest correlation ($r = 0.695$) with DFH, and significant associations with DFH, FC, NOH, FW, HD, and VL [22], indicating that sugar content may improve with longer vegetative development or delayed harvesting. However, TSS has non-significant correlations with FPP and YPH, reflecting a possible disconnect between sweetness and yield-oriented traits, in line with earlier findings [21].

The correlation analysis clearly indicates that YPH, FPP, and NOH are key determinants of productivity in cucumber, with strong interrelations among themselves and other traits like VL and HD. On the other hand, TSS, while related to traits like DFH and HD, appears to be largely independent of yield components, underlining a potential trade-off between yield and fruit quality. These insights are critical for breeding programs aiming to optimize both yield and quality traits in cucumber.

Path analysis

The diagram (Figure *3*) illustrates the relationships between multiple variables and their combined effects both direct and indirect on a central-dependent variable, yield in parthenocarpic cucumber. Each variable surrounding yield is connected through red arrows (direct effects) and green arrows (indirect effects), quantified with numerical coefficients that represent the magnitude and direction (positive or negative) of influence.

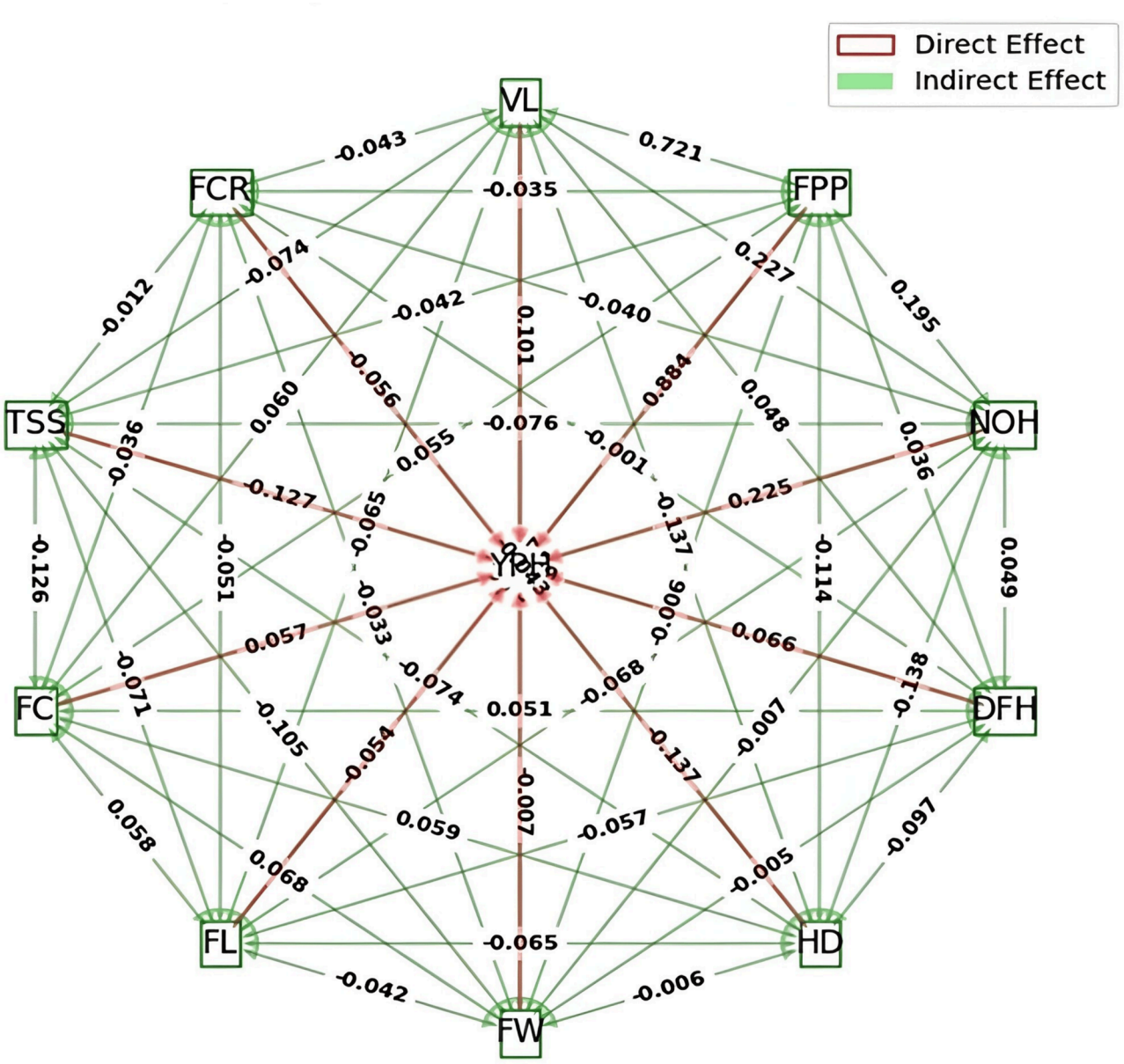


FIGURE 3: Estimates of direct and indirect effects.

VL, Vine Length; FPP, Fruit per Plant; NOH, Number of Harvests; DFH, Days to First Harvest; HD, Harvest Duration; FW, Fruit Weight; FL, Fruit Length; FC, Fruit Circumference; TSS, Total Soluble Solids; FCR, Flesh-to-Seed Cavity Ratio

Direct Effects on Yield

VL of cucumber has a positive direct effect on yield with a coefficient of 0.101, suggesting that increases in VL are associated with an increase in yield. FPP contributes highest positive direct effect of 0.884, indicating that it is a strong positive predictor of yield [22,26,27]. The NOH has a positive direct effect of 0.225, showing a good contribution to increased yield. DFH has a positive direct effect of 0.066, meaning that longer times to first harvest has less impact on yield. HD, FL, and FW have negative direct effects on yield. FC shows a positive direct effect of 0.057, while TSS has a direct effect of −0.127, implying a negative impact. Finally, the FCR has a slight negative direct effect of −0.056.

Indirect Effects on Yield

Cucumber VL has a significant indirect influence on yield through FPP with a coefficient of 0.721 [22], indicating that VL strongly enhances yield indirectly by promoting fruit production. FPP itself shows indirect effects through NOH (0.195), which contribute positively to yield. The NOH indirectly influences yield via FPP (0.764), suggesting a sequential effect where increased harvest frequency promotes fruit number and more productive harvesting phases. DFH is indirectly connected to FPP (0.486) and NOH (0.167), implying a cascade of influence where earlier harvesting can enhance yield through greater number of fruits and frequent harvests. HD, FW, FL, and FC also maintain indirect pathways through FPP [22] and NOH. Finally, TSS and FCR display relatively weaker indirect effects except via FPP.

Each variable interacts within this web of causality, and the combination of direct and indirect effects helps quantify the total influence on yield. For instance, a variable with a weak or negative direct effect could still have a strong total effect if it influences powerful mediators like FPP or NOH.

It can be deduced that FPP in cucumber has the strongest total influence (direct + indirect) in consonance with the earlier findings [22,23,25], especially given its central role in mediating other variables. VL, despite a small direct impact, contributes positively through its indirect effect via FPP. Variables like FL and FC, although with smaller direct effects, play supporting roles in the network of influences through indirect paths. Indirect pathways reveal hidden effects that would be missed by examining direct relationships alone. If the association between yield and a character is due to a character's direct effect, direct selection for the character will be beneficial for yield improvement. If, on the other hand, the correlation coefficient is mostly due to the character's indirect effect through another component trait, indirect selection through that character will be successful in improving yield [28].

Conclusions

Overall, the study revealed that among cucumber hybrids grown under passive greenhouses, Koyal emerged as the top performer, recording the highest yield, fruit number, and FW, while Sania excelled in VL, HD, and FCR, reflecting superior vegetative and fruit quality traits. Aviva demonstrated good FC and TSS, indicating potential for premium markets. The correlation and path analyses confirmed that FPP, NOH, and VL are the most influential traits determining yield under protected environments. These are the preliminary recommendations requiring validation across multiple seasons and locations in due course of time.

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

Concept and design: MS Kanwar

Acquisition, analysis, or interpretation of data: MS Kanwar, Nadeya Khaliq

Drafting of the manuscript: MS Kanwar

Critical review of the manuscript for important intellectual content: MS Kanwar, Nadeya Khaliq

Supervision: MS Kanwar

Disclosures

Plant subjects: All authors have confirmed that this study did not involve any herbarium specimen. **Human subjects:** All authors have confirmed that this study did not involve human participants or tissue. **Animal subjects:** All authors have confirmed that this study did not involve animal subjects or tissue. **Conflicts of interest:** In compliance with the ICMJE uniform disclosure form, all authors declare the following: **Payment/services info:** All authors have declared that no financial support was received from any organization for the submitted work. **Financial relationships:** All authors have

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Data Availability Statements

The datasets (and/or code) supporting this study are available from the corresponding author upon reasonable request.

References

1. Kanwar MS, Chichaghare AR, Mhetre VB, Jadhav MM: Greenhouse innovations are giving new life to farming in Ladakh. Down to Earth. 2025, https://www.downtoearth.org.in/agriculture/greenhouse-innovations-are-giving-new-life-to-farming-in-ladakh.
2. Kumar P, Khapte PS, Saxena A, Kumar P: Evaluation of gynoecious cucumber (Cucumis sativus) hybrids for early-summer greenhouse production in western Indian arid plains. The Indian Journal of Agricultural Sciences. 2019, 89:545-550. 10.56093/ijas.v89i3.87603
3. Sharma HG, Dubey P, Satpute P, Agrawal N: Off season production of cucurbitaceous crops under naturally ventilated greenhouse environment. International Conference on Plasticulture and Precision Farming. 2005, 72.
4. Kanwar MS, Sharma OC: Productivity of summer squash (Cucurbita pepo L.) under trench protected structure in cold desert Ladakh, India. Journal of Experimental Agriculture International. 2023, 45:98-101. 10.9734/jeai/2023/v45i122270
5. Akbar PI, Kanwar MS, Mir MS, Hussain A: Protected vegetable cultivation technology for cold arid agro-ecosystem of Ladakh. International Journal of Horticulture. 2013, 3:109-113.
6. Bisht B, Singh MP, Srivastava BK, Singh PK: Performance of cucumber varieties in a naturally ventilated polyhouse. Indian Journal of Horticulture. 2011, 68:575-577.
7. More TA: Development and exploitation of tropical gynoecious lines in F1 hybrid of cucumber. Acta Horticulturae. 2002, 588:261-267. 10.17660/actahortic.2002.588.40
8. Tian S, Zhang Z, Qin G, Xu Y: Parthenocarpy in Cucurbitaceae: advances for economic and environmental sustainability. Plants. 2023, 12:1-14. 10.3390/plants12193462
9. Nirmala, Choudhary S: Evaluation of parthenocarpic cucumber (Cucumis sativus L.) cultivars for summer cultivation under insect-proof net house in Indian hot arid region. Annals of Arid Zone. 2023, 61:53-59. 10.56093/aaz.v61i1.134197
10. Spehia R: Status and impact of protective cultivation in Himachal Pradesh, India. Current Science. 2015, 108:2254-2257.
11. Bertin N, Génard M: Tomato quality as influenced by preharvest factors. Scientia Horticulturae. 2018, 233:264-276. 10.1016/j.scienta.2018.01.056
12. Singh AK, Chandra P, Shrivastava R, Kumar R: Influence of varieties and spacing on yield and economics during off season cucumber production under protected condition in North Indian plains. Vegetable Science. 2015, 42:71-75.
13. Singh MC, Singh JP, Pandey SK, Mahay D, Varun S: Factors affecting the performance of greenhouse cucumber cultivation-a review. International Journal of Current Microbiology and Applied Science. 2015, 6:2304-2323.
14. Kumar P, Khapte PS, Singh A, Saxena A: Optimization of low-tech protected structure and irrigation regime for cucumber production under hot arid regions of India. Plants. 2024, 13:1-15. 10.3390/plants13010146
15. Gangadhara K, Kumar Raj, Selvakumar R, Apparao VV, Yadav LP: Evaluation of cucumber hybrids/lines for yield and quality under polyhouse. International Journal of Current Microbiology and Applied Science. 2019, 8(6):1652-1661. 10.20546/ijcmas.2019.806.197
16. Kumar S, Kumar R, Dogra RK: Heterotic potential, potence ratio, combining ability and genetic control of seed vigour traits for yield improvement in cucumber (Cucumis sativus). The Indian Journal of Agricultural Sciences. 2018, 88:771-778. 10.56093/ijas.v88i5.80088
17. Zhang Y, Henke M, Li Y et al.: Analyzing the Impact of Greenhouse Planting Strategy and Plant Architecture on Tomato Plant Physiology and Estimated Dry Matter. Frontiers in Plant Science. 2022, 13:828252. 10.3389/fpls.2022.828252

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18. Rouphael Y, Kyriacou MC, Petropoulos SA, De Pascale S, Colla G: Improving vegetable quality in controlled environments. Scientia Horticulturae. 2018, 234:275-289. 10.1016/j.scienta.2018.02.033

19. Gautam I, Pradhan N, Subedi S, Thakur M: Evaluation of cucumber hybrids for yield and quality under plastic house and open field conditions. Nepalese Horticulture. 2021, 15:52-63. 10.3126/nh.v15i0.36649

20. Osman M, Qaryouti M, Alharbi S, et al.: Impact of CO2 enrichment on growth, yield and fruit quality of F1 hybrid strawberry grown under controlled greenhouse condition. Horticulturae. 2024, 10:1-14. 10.3390/horticulturae10090941

21. Kumar S, Singh P, Bhardwaj A: Genetic variability and character association in parthenocarpic cucumber (Cucumis sativus L.) under protected cultivation. Plant Archives. 2024, 24:210-217. 10.51470/plantarchives.2024.v24.sp-gabels.032

22. Mehta P, Sharma P, Kaur M, Shilpa S, Sharma A, Bhardwaj N: Correlation and path analysis studies in parthenocarpic cucumber (Cucumis sativus L.). Vegetable Science. 2022, 49:116-119. 10.61180/vegsci.2022.v49.i1.19

23. Karthick K, Arumugam T, Rajasree V, Ganesan KN, Karthikeyan M: Studies on correlation and path analysis of yield attributes in cucumber (Cucumis sativus L.). Journal of Pharmacognosy and Phytochemistry. 2019, 8:342-345.

24. Ghimire HP, Acharya N, Sapkota R: Performance evaluation of cucumber genotypes and study on correlation and path analysis. International Journal of Horticulture. 2024, 14:218-222.

25. Lnu R, Dhall RK, Manchanda P, Kumari P, Singathiya P: Study on characters associations and path coefficient analysis for yield and quality traits of parthenocarpic cucumber genotypes in poly-net house conditions. Discover Plants. 2025, 2:1-15. 10.1007/s44372-025-00103-9

26. Veena R, Sidhu AS, Pitchaimuthu M, Souravi K: Character association for fruit yield and yield traits in cucumber (Cucumis sativus L.). Electronic Journal of Plant Breeding. 2013, 4:1108-1112.

27. Sharma S, Kumar R, Chatterjee S, Sharma HR: Correlation and path analysis studies for yield and its attributes in cucumber (Cucumis sativus L.). International Journal Chemical Studies. 2018, 6:2045-2048.

28. Keshari D, Singh B, Singh R, et al.: Path analysis studies for fruit yield and its contributing traits in cucumber (Cucumis sativus L.). Annals of Horticulture. 2020, 13:56-60. 10.5958/0976-4623.2020.00008.0

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