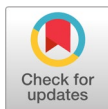


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Performance Evaluation of Indeterminate Tomato Hybrid Varieties under Walk-In Tunnel in the Agro-climatic Condition of DI Khan, Pakistan

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ABSTRACT

This study assessed the yield and yield components of eight indeterminate tomato hybrids—Salar F1 (H1), Sandal F1 (H2), Surkhail F1 (H3), Kormescvije (H4), Stupice (H5), Creole (H6), Moskvich (H7), and Black Prince (H8)—under plastic tunnel conditions in DI Khan, Pakistan during the years 2021-2022. Randomized Complete Block Design (RCBD) was used with three replications. The study measured days to flowering, days to fruiting, plant height, leaf length, number of fruits per plant, average fruit weight, yield per plant, and yield per plot. Sandal F1 had the shortest time to flowering and fruiting (40 and 60 days, respectively), followed by Surkhail and Salar F1 with intermediate values (43 and 63-64 days). Plant height was the highest in Kormescvije (226.63 cm) and lowest in Creole (157.77 cm), with Salar F1, Black Prince, and Stupice in between them. Stupice had the longest leaf length (14.03 cm), followed closely by Sandal F1, while Surkhail had the shortest leaf length (8.93 cm). Stupice produced the most fruits per plant (153.00), significantly more than Salar F1 and Sandal F1 (83.00 and 94.00, respectively), while Kormescvije produced the fewest (14.00). Kormescvije had the highest average fruit weight (114.2 g), followed by Creole and Moskvich (106.03 g and 98.20 g, respectively), with Salar F1, Sandal F1, and Surkhail F1 showing intermediate average fruit weights. Whereas, Stupice had the smallest fruits (20.20 g). Yield per plant was the highest in Sandal F1 (2.93 kg), followed by Salar F1 (2.40 kg) and Surkhail (2.00 kg), with Moskvich giving the lowest yield (0.63 kg). Overall, Sandal F1 achieved the highest yield per plot (12.90 kg), followed

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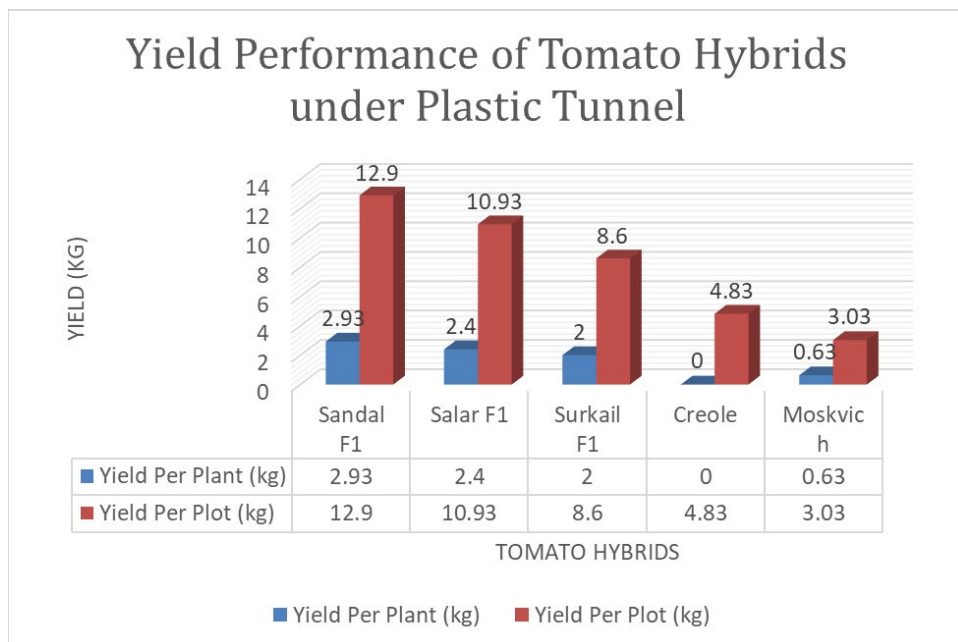
by Salar F1 (10.93 kg) and Surkhail (8.60 kg), while Moskvich and Creole gave the lowest yield (3.03 kg and 4.83 kg, respectively). The study concluded with Sandal F1 as the most productive hybrid under the given conditions, significantly outperforming other varieties, whereas Moskvich showed the lowest performance across most parameters. The means were significantly different at 5% level of significance, indicating distinct performance among the evaluated varieties.

Keywords: growth parameters, indeterminate tomato varieties, off season tomato cultivation, yield parameters

Highlights

- Eight indeterminate tomato hybrids were evaluated under plastic tunnel conditions in DI Khan.
- Sandal F1 recorded the highest yield per plant (2.93 kg) and per plot (12.90 kg).
- Stupice produced the most fruits per plant (153), while Moskvich had the lowest yield.

GRAPHICAL ABSTRACT



1. INTRODUCTION

Tomato (*Solanum lycopersicum L.*) is one of the most important vegetable crops cultivated around the world for its nutritional value, economic importance, adaptability, and multiple applications. It is used fresh and for various food processing purposes including sauces, pastes, juices, ketchup, canned goods, and other food preparations. Tomato fruits contain significant amounts of vitamins A and C, potassium, folate, minerals, dietary components, as well as antioxidants. Of these bioactive compounds, lycopene is of special interest due to its anti-oxidant function and its connection to human health [1]. The consumption of tomato and tomato products has been associated with benefits to cardiovascular health and protection against oxidative stress (Willcox et al., 2003). The nutritional and economic properties of tomato make it an important crop in many parts of the globe.

The Food and Agriculture Organization (FAO) of the United Nations (UN) estimated that 186 million metric tons of tomatoes were produced worldwide in 2020 on some 5.1 million hectares of land. As demonstrated by the large cultivation area dedicated to tomato production and its global production, tomato is an important crop. Tomato can be cultivated in various climatic zones, from temperate to subtropical and tropical zones [2]. It is also easily grown in open field and in protected production systems, making it a significant commercial vegetable crop (FAO, 2021).

Tomato is a significant horticultural crop in Pakistan and plays a significant role in vegetable production and farmers' livelihood. Tomatoes are grown at various times of the year and under a variety of production conditions. The Ministry of National Food Security and Research (MNFSR, 2022) reported a total area of 9,674 ha and production of 232,098 tons of tomato in the Kharif season, while an area of 47,739 ha and production of 564,183 tons were reported in the Rabi season during the period 2021-2022. These statistics highlight the significance of producing tomatoes to supply household vegetable consumption and to support farm livelihoods [3].

Khyber Pakhtunkhwa (KP) is one of the significant tomato producing provinces of Pakistan. The province has a wide range of agro-climatic conditions which enable the production of tomato at various places and times. MNFSR (2022) revealed that 10,401 ha of land were sown with tomato and 89,360 tons of tomato were produced during the Kharif season,

while 2760 ha were sown during the rabi season and 30,144 tons of tomato were produced. In Dera Ismail Khan (DI Khan), 549 ha were cultivated and 3,892 tons of tomatoes were produced (MNFSR 2022). These figures bear witness to the importance of tomato production in the agricultural economy of the region and highlight the potential for increasing the productivity of the crop using appropriate varieties and improved production practices.

Protected cultivation has become an important means of increasing crop productivity, improving produce quality, and protecting crops from unfavorable environmental conditions [4,5]. Protected structures, such as plastic tunnels, greenhouses, net houses, polyhouses, and other similar constructions can adjust the environment in which the crop is grown, offering more control of temperature, humidity, wind, and other environmental factors [4,5]. Tomato production in protected cultivation may even lengthen the production season and enable growers to plant tomatoes using these structures when it isn't possible to grow them in the open field [4]. Protected cultivation can also boost production stability and create market potential for fresh tomato supply in comparison to low market season. Recently, it has been shown that protected structures can be used to enhance tomato production, especially in the event of poor weather and during off-season [4].

Indeterminate tomato varieties are especially well-adapted for protected production because they sustain vegetative growth and flower and produce fruit over a long period of time in right conditions [6]. They have a continuous growth habit that can be harvested repeatedly and can yield a long production period. It is important to note, however, that indeterminate plants usually need to be supported, trained, pruned and managed, in order to ensure a healthy and efficient plant structure within the tunnel. Different plant varieties have different genetic traits that impact plant growth, flowering, fruit set, fruit size, and yield, which can significantly affect their performance [5,6].

A good selection of appropriate indeterminate hybrids is of special significance for DI Khan, since climatic conditions here may pose challenges for out-of-season tomato cultivation. The cool and warm weather, low and high humidity, heavy pest and disease load, and diverse crop growing conditions affect yield and fruit quality. The mean outdoor temperature was 19.7°C in November 2021, which dropped to 14.1°C in December, and a new monthly record low mean temperature of 13.2°C was

set in January 2022. The temperature then slowly began to rise to 16.2°C in February and 25.0°C in March. The monthly mean maximum temperature varied from 18.9°C in January to 33.0°C in March, while the monthly mean minimum temperature varied from 6.0°C in December to 17.1°C in March. The changes show a significant difference in the overall ambient temperature throughout the growing season.

Protection from these environmental stresses can be partly achieved using plastic tunnels, however, the effectiveness of the system is highly dependent on the genotype grown [5,6]. It is, therefore, essential to test the various indeterminate hybrids under local tunnel conditions so that the ones which can give better yield and growth can be identified. With these considerations in mind, the present study was carried out to assess the yield and yield components of eight indeterminate tomato hybrids, namely Salar F1 (H1), Sandal F1 (H2), Surkhail F1 (H3), Kormescvije (H4), Stupice (H5), Creole (H6), Moskvich (H7), and Black Prince (H8) under plastic tunnel conditions in DI Khan, Pakistan. Important growth and yield parameters, such as days to flowering, days to fruiting, plant height, leaf length, number of fruits per plant, average fruit weight, yield per plant, and yield per plot were evaluated. A Randomized Complete Block Design (RCBD), with three replications, was used to compare the performance of the tested hybrids in similar environmental and management situations.

The aim of this study is to find the most suitable overall performance hybrid in the agro-climatic conditions of DI Khan. The outcomes of the experiment can be beneficial to farmers, horticultural researchers, extension workers, and other stakeholders involved in the cultivation of tomatoes in protected areas. The identification of superior hybrids will facilitate farmers to choose the right variety, increase the off-season tomato yield, and improve production efficiency in plastic tunnels. Finally, the assessment of indeterminate tomato hybrids in local conditions can help to optimize tomato production, maximize the use of protected cultivation technologies, and enhance the availability of fresh tomato when open field production becomes challenging.

1.1. Objectives

The primary objectives of this study are to: 1) identify high-yielding indeterminate hybrid tomato varieties, and 2) evaluate and compare the growth and quality attributes of these tomato indeterminate hybrids under

the agro-climatic conditions of D.I. Khan.

2. MATERIALS AND METHODS

The yield performance and yield related characters of eight indeterminate tomato hybrids (Salar F1, Sandal F1, Surkhail F1, Kormescvije, Stupice, Creole, Moskvich, and Black Prince) were tested for their performance under plastic tunnel conditions. The experiment was carried out in an experimental tunnel in the Horticulture Section of the Agricultural Research Institute (ARI), DI Khan, Pakistan, with a tunnel size of 60 × 12 × 10 (60 ft in length, 12 ft in width, and 10 ft in height). The study attempted to compare the growth, flowering, fruiting, and yield potential of the tomato hybrids selected under protected cultivation. The nursery was prepared by causing the seeds to germinate on October 28 and healthy seedlings were planted in the plastic tunnel in November. A Randomized Complete Block Design (RCBD) with 8 treatments (tomato hybrids) and 3 replications was used to provide accuracy in comparison between the tomato hybrids. The row-to-row spacing was 100 cm and the plant-to-plant spacing was 40 cm, which was deemed sufficient for plant growth and development. Irrigation was done as per crop requirements, normally at a 6-7 day interval as per environmental conditions and soil moisture. Nitrogen, phosphorus, and potassium fertilizers (75:50:50) were applied using urea, diammonium phosphate (DAP), and sulphate of potash (SOP), respectively. Good crop management was carried out during the entire growing period to ensure the healthy development of the plants and their fruit production. The vegetative, flowering, fruiting, and yield parameters were measured and the performance of the eight tomato hybrids was evaluated under the plastic tunnel environment.

2.1. Days to Flowering

The number of days from transplanting to initial flowering were noted for each tomato hybrid. Observations were made frequently to identify the time it takes each hybrid to start flowering under plastic tunnel conditions. The earliness of the hybrids was used to compare this parameter and to determine those varieties that can flower in a shorter time after transplanting.

2.2. Days to Fruiting

The number of days from transplanting to first fruit were recorded for each tomato hybrid. Plants were observed regularly to determine the first

fruit setting phase. The data were utilized to check differences in fruit production between the hybrids and to compare their performance against each other in early fruit production in protected cultivation.

2.3. Plant Height (cm)

Plant height (inches) was determined from the point of the soil to the growing tip of the plant with a measuring tape. Data was collected from five plants taken randomly from each treatment. Plant height was taken in cm and the mean height value of each hybrid was calculated. The parameter was used to assess the vegetative growth and differences in growth stages between the tested hybrids.

2.4. Leaf Length (cm)

The length of the leaves was recorded on a measuring tape in cm. Representative leaves were taken from plants and their lengths were carefully measured. The average leaf length was then determined for each hybrid. This measurement was used to determine the differences in leaf development and vegetative growth of the tomato hybrids.

2.5. Number of Fruits per Plant

During all harvestings, the number of fruits per plant were counted. The number of fruits were counted separately for each hybrid and the total fruit plant count was made during the harvest season. This parameter was used to compare the fruit bearing capacity and productivity of the different tested hybrids.

2.6. Average Fruit Weight (g)

Five fruits from each hybrid were chosen to be weighed on an electronic balance. The weights of the individual fruits were noted and the mean weight of the fruits was recorded in grams. Afterwards, fruit size and weight of the hybrids were compared with the parameter.

2.7. Yield of Individual Plants (kg)

The yield per plant was measured in kg to determine the productivity of each tomato hybrid in plastic tunnel farming conditions. Harvesting was carried out at suitable maturity stages and the yield was obtained from individual plants during the harvesting period, which was measured and recorded. Care was taken in harvesting to prevent fruit damage and to obtain accurate measurements. The yield of each plant was measured individually

for each hybrid and the final yield per plant was calculated by adding up the weight of fruits obtained from successive harvests. The recorded data was compared with the productivity of the eight tomato hybrids and those yielding higher plant productivity were determined. This was a measure of the fruit production ability of each hybrid in experimental conditions.

2.8. Yield per Plot (kg)

The yield of plots collected at each harvest stage was recorded in kg and the overall yield of the tomato hybrids was calculated. All mature fruits from plants in each experimental plot were harvested, weighed using a proper weighing scale, and recorded separately for each treatment. Weights from successive harvests were totaled to determine the total yield per plot. All treatments were harvested and weighed in the same way to ensure the uniformity of data collection. The overall performance of the eight hybrids under plastic tunnel cultivation was evaluated using the plot yield. The measurements were utilised to determine the differences in total fruit production and as a basis to assess the yield potential of each hybrid under experimental conditions.

3. RESULTS AND DISCUSSION

The eight tomato hybrids (H1 to H8) were found to differ for the number of days taken to flower and fruit in plastic tunnel conditions at Agricultural Research Institute (ARI), DI Khan, Pakistan. The tested hybrid found to have the earliest flowering and fruiting was Sandal F1 at 40 and 60 days, respectively. F1s Surkhail and Salar also showed relatively early flowering and fruit setting over the rest of the hybrids. The observations suggest that there are differences in the reproductive development of tomato hybrids in experimental conditions.

The observed variation in flowering and fruit setting time indicates that reproductive development of the eight tomato hybrids in plastic tunnel conditions varied. The earliest flowering and fruiting was exhibited by Sandal F1, which could be beneficial in situations where early crop production and market supply is a priority. Better flowering and fruiting could reduce the time from transplanting to the first harvest, although this needs to be tested in the field with harvest time and yield data to determine the effect of earlier flowering and fruiting on earliness and total productivity [7].

Genetic variation between tomato hybrids can also be related to

differences in reproductive timing. This is due to differences in developmental reaction to temperature, light availability, and other environmental conditions. Seasonal differences in temperature experienced during the course of the experiment could have also affected the timing of flowering and fruit development. However, the relative humidity and temperature in the plastic tunnel were not measured directly, so the specific effect of the plastic tunnel microclimate could not be determined. Moreover, the observed differences were not sufficient to prove that any particular hybrid is more tolerant of the prevailing agro-climatic conditions. The results showed that the hybrid Sandal F1 is the first to flower and bring fruits among the tested hybrids, while Surkhail F1 and Salar F1 also showed relatively early reproductive development. However, early flowering and fruiting alone cannot be regarded as being representative of overall hybrid superiority. Fruit number, fruit weight, and total yield, as well as other measured traits, should be collected and compared to the results of this test to check the overall performance of the tested hybrids.

3.1. Days to Flowering (Days)

There was considerable variance between the flowering days of the eight indeterminate tomato varieties. The range in varieties for first flowering was 40-60 days. The lowest flowering time was recorded for Sandal F1 with only 40 days to flowering, while Creole recorded the highest flowering time of 60 days. Other varieties had an intermediate flowering time, suggesting differences in their reproductive development under plastic tunnel conditions. Since flowering is a significant developmental trait that is genetically determined, differences in flowering time could be due to genetic differences between the varieties [9,10]. Early flowering can sometimes be beneficial in off-season tomato production, as it can help to initiate fruit production and harvest earlier. The observed differences between the varieties, therefore, indicate that Sandal F1 might perform better in terms of early reproductive performance under the agro-climatic conditions of DI Khan, while Creole might need a comparatively longer time for its initiation of flowering.

3.2. Days to Fruiting (Days)

The data presented in Table 1 reveals significant variation among the eight indeterminate tomato varieties in terms of the number of days to fruiting. Sandal F1 reached fruiting in 60 days, while Creole took the most

days thus reducing its market value, as earlier fruiting varieties may have a competitive advantage in terms of time to market [9,10].

Table 1. Mean Data Regarding Days to Flowering, Days to Fruiting, Plant Height, Leaf Length and Number of Fruits Plant of Eight Indeterminate Tomato Varieties

Variety	Days to Flowering	Days to Fruiting	Plant Height (cm)	Leaf Length (cm)	Number of Fruits Plant ⁻¹
Salar F1	43.00 cd	64 cd	198.83 ab	11.93 d	83.00 b
Sandal F1	40.00 d	60 d	212.17 a	13.30 b	94.00 b
Surkhail	43.00 cd	63 cd	181.10 ab	8.93 f	88.00 b
Kormesviye	46.00 c	66 cd	226.63 a	10.20 e	14.00 c
Stupice	55.00 ab	76 ab	206.63 ab	14.03 a	153.00 a
Creole	60.00 a	80 a	157.77 b	12.23 d	17.00 c
Moskvich	57.00 ab	77 ab	178.87 ab	12.70 c	19.00 c
Black Prince	53.00 b	74 b	199.97 ab	10.26 e	34.00 c

Note. Means followed by different letters are significantly different from each other at 5% level of significance.

3.3. Plant Height (cm)

Plant height measurements indicated that Sandal F1 had the tallest plants (212.17 cm), while Creole had the shortest plants (157.77 cm). The variability in plant height is consistent with findings from other studies showing genetic differences significantly impacting plant stature [9]. Taller plants, such as those of Sandal F1, may have advantages in terms of yield potential and light capture, but they might also require more support and management.

3.4. Leaf Length (cm)

Leaf length ranged from 8.93 cm in Surkhail to 14.03 cm in Stupice. Stupice had the longest leaves, which could enhance photosynthesis and overall plant health, potentially contributing to higher yields [9,10]. Leaf length, along with other growth parameters, can significantly influence the overall productivity of tomato plants.

3.5. Number of Fruits per Plant (Nos.)

The number of fruits per plant showed substantial variation. Stupice produced the highest number of fruits per plant (153.00), while Black Prince

had a relatively lower fruit count (34.00). The higher fruit count in Stupice suggests it might have superior fruit-setting capabilities or better overall fruit production efficiency, as compared to other varieties [11]. This trait is crucial to determine the economic viability of tomato varieties, as higher fruit numbers often correlate with higher yields.

3.6. Average Fruit Weight(g)

The average fruit weight varied significantly among the tomato varieties, ranging from 20.20 g in Stupice to 114.20 g in Kormesvije. Kormesvije produced the heaviest fruit, followed by Creole with an average fruit weight of 106.03 g. In contrast, Stupice produced the smallest fruit. The large fruit size of Kormesvije and Creole may be advantageous for markets that value large fruits, but these varieties also need to balance size with overall yield and plant productivity (Johnson et al., 2019).

3.7. Yield per Plant (kg)

The yield per plant was found to be significantly different among the eight tomato hybrids grown in plastic tunnel. The highest yield of 2.93 kg/plant was produced by Sandal F1, while Moskvich gave the lowest yield of 0.63 kg/plant, followed by Creole with a yield of 0.76 kg/plant. Sandal F1 produced more yield as compared to the other varieties, suggesting that it was more productive than the other varieties in experimental conditions. This was likely due to its relatively early flowering and fruiting which should be considered in conjunction with fruit number and average fruit weight, not exclusively as a result of earliness.

Creole had a relatively low yield but also had one of the highest average fruit weights (106.03 g). So, its lower productivity cannot be attributed to smaller fruit size. Rather, it could be linked to a reduction in fruits per plant or in other yield components, as these should also be evaluated with the recorded data. Likewise, the poor production of Moskvich needs to be judged against fruit number and average fruit weight [12]. The results indicated that the overall yield is determined by both fruit number and fruit weight. Whether or not a hybrid fruit with greater fruit size may yield less overall, or whether or not a hybrid fruit would compensate for the smaller fruit size with more fruits, depends on the specific fruit. When plant yield was averaged across all the combinations of hybrids and fertilizers, Sandal F1 was determined as the highest yielding hybrid and Moskvich as the lowest yielding under the conditions of this experiment [13].

3.8. Yield per Plot (kg)

The yield per plot, which is crucial for assessing overall productivity, ranged from 3.03 kg in Moskvich to 12.90 kg in Sandal F1. Sandal F1's superior performance in terms of yield per plot highlights its potential for higher total production, which is beneficial for commercial cultivation. In contrast, Moskvich and Creole had lower yields per plot, possibly affecting their economic viability [14,15].

Table 2. Mean Data Regarding Average Fruits Weight, Yield per Plant, Yield per Plot of Eight Indeterminate Tomato Varieties

Variety	Average Fruit Weight (g)	Yield per Plant (Kg)	Yield per Plot ¹ (kg)
Salar F1	79.87 c	2.40 b	10.93 ab
Sandal F1	76.2 c	2.93 a	12.90 a
Surkhail	77.5 c	2.00 bc	8.60 abc
Kormesviije	114.2 a	1.46 d	7.50 bc
Stupice	20.20 d	1.63 cd	7.66 bc
Creole	106.03 ab	0.76 ef	4.83 c
Moskvich	98.20 b	0.63 f	3.03 c
Black Prince	86 c	1.20 be	7.30 bc

Note. Means followed by different letters are significantly different from each other at 5% level of significance.

3.1. Conclusion

This study evaluated eight indeterminate tomato hybrids under plastic tunnel conditions in DI Khan, Pakistan during the 2021-22 growing season. Sandal F1 showed the shortest time to flowering and fruiting (40 and 60 days respectively), as well as the highest yield per plant (2.93 kg) and per plot (12.90 kg), which was closely followed by hybrid Salar F1 and Surkhail. Kormescviije produced the tallest plants (226.63 cm). The higher mean yield per plant (2.93 kg) and the highest mean fruit weight (114.2 g) was observed in Sandal F1, which showed promising yield performance in plastic tunnel conditions. Among tested indeterminate tomato hybrids, Salar F1 and Surkhail F1 exhibited a good production potential. Although Stupice had the highest fruit number per plant (153.00), the lowest fruit weight was 20.20 g, showing that the number of fruits is not necessarily proportional to the total yield. Moskvich recorded the lowest yield per plant (0.63kg) and per plot (3.03kg), showing that its productivity under experimental

conditions was comparatively lower as compared to other varieties. The differences in mean yields, however, must be interpreted based on the statistical results; if there is overlap in the letter groupings for yield per plot, then some hybrids may not differ significantly. Thus, it can be inferred that the hybrid Sandal F1 is the highest yielding with respect to its mean performance, while Salar F1 and Surkhail F1 also showed their potentiality. These results can be further validated by testing the same hybrids in other seasons and in other locations.

4.2. Recommendations

Based on its superior performance in yield and early production, Sandal F1, Salar F1, and Surkhail are recommended for commercial cultivation in off-season conditions in DI Khan, Pakistan. Its ability to produce high yields with early fruiting can optimize the Return on Investment (ROI) and enhance market competitiveness. However, since the study was conducted at only one location during a single growing season, further research is needed to confirm their performance. Testing these hybrids over several seasons and at different locations would help determine their adaptability, yield stability, and economic benefits. Although Kormesviye had a lower yield per plant, its large fruit size makes it suitable for those markets where fruit size is highly valued. Growers targeting such markets might find this variety beneficial. Additional studies should be conducted to explore the long-term sustainability of these varieties under varying environmental conditions in order to assess their performance over multiple growing seasons.

Author Contribution

Rashid Khan: Conceptualization, Methodology, Investigation, Data curation and Writing-original draft. **Mohammad Arif:** Data curation. **Sheheryar Hafeez:** Data curation. **Adil Reman:** Supervision, Writing-review & editing. **Imranullah:** Supervision, Writing-review & editing. **Farkhanda Khan:** Methodology, Data curation. **Basit Ali Afridi:** Data curation, Writing-original draft. **Aamir Khan Khalil:** Data curation. **Riaz Ahmad Afridi:** Project administration, Assist in Formal analysis. **Faiza Khan Khalil:** Data curation. **Albarr Afridi:** Formal analysis. **Hamza Ahmad Khan:** Data curation.

Conflict of Interest

The authors of the manuscript have no financial or non-financial conflict of interest in the subject matter or materials discussed in this manuscript.

Data Availability Statement

The data analyzed during this study are available from the corresponding author upon request.

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Generative AI Disclosure Statement

The authors did not use any type of generative artificial intelligence software for this research.

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