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Efficiency of the 'triploid hybrid–pollenizer' system in seedless watermelon production technology

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Abstract. The article presents results of a three-year (2023–2025) study on the effect of diploid pollenizer hybrids on productivity, fruit quality triploid (seedless) watermelon hybrids in the Forest-Steppe zone of Ukraine. The study aimed to substantiate the role of pollenizers in realizing the productive and qualitative potential of seedless hybrids. Two triploid hybrids (Extazy and Pekin) and three diploid pollenizers (Premium, Yummy, and Tatum) were planted in a 2.0×0.7 mscheme with a triploid-to-diploid ratio of 3:1. The experimental plot area was 400 m^2, with four replications. The response of triploid hybrids to pollenizer type was not statistically significant in the combined three-year analysis, and the 'hybrid × pollenizer' interaction was also not significant. At the same time, seedless fruit yield was significantly influenced by annual environmental conditions and the genotypic characteristics of the hybrid. Premium provided the highest yield of seedless hybrids (Extazy – 60.83 t ha^{-1}; Pekin – 61.16 t ha^{-1}), whereas Yummy and Tatum, despite their higher individual productivity, were less efficient in the 'triploid hybrid-pollenizer' system. Fruit weight of triploid hybrids was characterized by genetic stability and was minimally affected by pollenizer type, whereas diploid pollenizers demonstrated greater variability. Soluble solids content in seedless fruits consistently exceeded 11.5 °Brix and was primarily determined by the triploid hybrid genotype and annual environmental conditions. These findings provide a scientific basis for targeted pollenizer selection as an important factor in optimizing the cultivation technology of triploid seedless watermelons.

Key words: fruit weight, yield, °Brix, pollenizer.

INTRODUCTION

The main goal of food production, which includes the cultivation of a wide range of vegetable crops, including watermelon, is the intensification of overall output. Over time, agricultural production has increasingly focused on enhancing the content of

phytonutrients in vegetables. This can be achieved through the optimization of agroecological conditions by applying appropriate agronomic practices.

Watermelon (*Citrullus lanatus* L.) is an important vegetable crop grown for its ripe, sweet, and palatable fruits with a pleasant aroma and refreshing taste. Currently, numerous seeded and seedless watermelon cultivars and hybrids are available. In recent years, seedless hybrid watermelons have become increasingly attractive to the market, as they meet consumer demands on the one hand and the needs of producers and traders on the other (Coşkun & Gülşen, 2024; Coşkun, 2025). Commercial production of seedless watermelons began in the 1990s (Guan et al., 2020) and has been steadily increasing since then, currently accounting for a substantial share of the watermelon market. Although the first seedless hybrids were characterized by significantly lower sugar content and less sweetness compared with seeded cultivars, breeders have markedly improved these traits, so that this limitation is no longer observed in modern hybrids (De Paula et al., 2020). An evaluation of thirty-five seedless watermelon cultivars under the conditions of Central Kentucky demonstrated consistently high yield and quality performance (Saha et al., 2017).

Flesh color is one of the most important indicators of watermelon fruit quality and represents a major target in modern breeding programs. According to Ashoka et al. (2022), eight principal flesh color phenotypes have been identified in *Citrullus lanatus*: white, salmon yellow, orange, crimson red, scarlet red, pale yellow, canary yellow, and green. Each of these phenotypes is characterized by a distinct biochemical composition and nutritional value. Red-fleshed watermelons are the primary source of lycopene, orange-fleshed genotypes are rich in β-carotene, whereas yellow-fleshed fruits contain high concentrations of xanthophylls and β-carotene, compounds with pronounced antioxidant activity that play an important role in reducing the risk of certain ocular disorders and cancer (Correa et al., 2020; Manivannan et al., 2020; Fulgoni & Fulgoni, 2022).

Driven by the growing demand for functional foods, one of the primary objectives of contemporary watermelon breeding is the development of genotypes with enhanced nutritional and biological value (Tlili et al., 2023). However, progress in this direction is constrained by the complex polygenic inheritance of flesh color and the occurrence of genetic interactions during trait transmission (Khan et al., 2023). In particular, segregating populations for red and salmon-yellow flesh frequently exhibit atypical phenotypes, making the development of genetically stable and uniform cultivars considerably more difficult (Song et al., 2023).

In Ukraine, the commercial assortment of watermelon cultivars is still dominated by red-fleshed genotypes (Linnik et al., 2021). Nevertheless, increasing consumer awareness of the health benefits associated with natural antioxidants and carotenoids has stimulated growing interest in yellow-fleshed watermelons, which are distinguished by their high nutritional value and considerable potential for future breeding programs (Sanchez-Ballesta et al., 2022).

Triploid watermelon hybrids are cultivated exclusively through transplants due to the low germination energy of the seed and its high cost. Seed prices range from USD 1,540 to 2,640 per kg, and each transplanted plant costs USD 0.28–0.35 per plant (Stone et al., 2019).

Ernest (2023) reports that, under commercial field conditions, 20–30% of the area planted with seedless watermelons is allocated to seeded pollenizer cultivars. The fruits of pollenizers are marketed as a separate product and are not included in the main yield category. However, in large-scale production of seedless watermelons, particularly in arid and desert regions, pollenizers that do not produce marketable fruits at all are sometimes used.

The situation is markedly different in the United States, where seedless watermelons account for more than 80% of commercial production, with some estimates exceeding 85%. In contrast, seeded watermelons continue to occupy a substantial share of the market in many countries across Asia, Africa, and South America. Consequently, the global proportion of seedless watermelon production is considerably lower than that observed in the United States, although its exact share has not been reported in peer-reviewed scientific publications (Market Growth Reports, 2025, Wijesinghe et al., 2020). Seedless fruits are formed on triploid plants; however, pollination and fertilization are required for fruit set. Since triploid plants produce only a limited amount of viable pollen, the planting of diploid pollenizer plants is necessary (Wijesinghe et al., 2020). To ensure sufficient pollen supply for achieving maximum yields of triploid fruits, plants should be established at a ratio of one pollenizer to two to four triploid plants, and the choice of pollenizer cultivar significantly affects the yield of triploid fruits (Fiacchino & Walters, 2003).

Despite numerous remaining gaps in seedless watermelon cultivation technology that warrant further investigation, the objective of this study was to analyze the effect of pollenizer type on productivity formation in different triploid (seedless) watermelon hybrids under the conditions of the Forest-Steppe zone of Ukraine.

Unlike most published studies (Fiacchino & Walters, 2003; Freeman et al., 2007; Guan et al., 2020; Ernest, 2023), in which pollenizer performance was evaluated primarily based on the yield of triploid fruits or the number of fruit set, the present study provides a comprehensive assessment of the ‘triploid hybrid-diploid pollenizer’ system, including the simultaneous evaluation of:

- ✓ seedless fruit yield;
- ✓ individual productivity of diploid pollenizers;
- ✓ total productivity of the entire production system
- ✓ soluble solids content (°Brix) and the expression of metaxenia;
- ✓ productivity stability over three consecutive growing seasons.

Furthermore, whereas most previous studies were conducted under the subtropical or arid climatic conditions of the United States and Asia, the present research was carried out for the first time under the agroclimatic conditions of the Right-Bank Forest-Steppe of Ukraine, characterized by a temperate continental climate, unstable moisture availability, and pronounced interannual weather variability. Consequently, the obtained results have direct practical significance for adapting seedless watermelon production technology to the environmental conditions of Ukraine and other regions of Central and Eastern Europe. Moreover, they provide a scientific basis for the evidence-based selection of efficient combinations of triploid watermelon hybrids and diploid pollenizers to maximize productivity and fruit quality.

MATERIALS AND METHODS

Research on the selection of effective pollenizers for seedless watermelon was carried out in 2023–2025 at the Department of Vegetable Growing of Uman National University (Right-Bank Forest Steppe of Ukraine) by national methods (Bondarenko & Yakovenko, 2001). The soil was podzolized heavy loam chernozem with a well-developed humus horizon (about 2.9% of humus) (Krupskiy & Polupan, 2018), (Table 1), in the deep of 40–45 cm. Soil pH was determined in water (soil to water ratio 1:1). The electrical conductivity (ECe) of the soil suspension was measured using the conductivity meter. The P and K were determined by the ammonium bicarbonate-diethylenetriaminepentaacetic acid (ABDTPA) method (Ryan et al., 2001).

Table 1. Chemical properties of soil

Parameter	Value ($x \pm SD$)
Organic carbon %	2.2 ±0.12
Acidity (pH)	6.1 ± 0.10
ECe, μS cm^{-1}	24 ± 0.45
Extractable P (ABDTPA), mg kg^{-1}	102 ± 3.33
Extractable K (ABDTPA), mg kg^{-1}	123 ± 2.0
NO_3N, mg kg^{-1}	64 ± 1.53

Experimental design

Standard seedlings were transplanted in the third decade of May according to the following planting scheme: 2.0 × 0.7 m, corresponding to a density of 7,143 plants per hectare (5,357 seedless plants and 1,786 pollenizer plants). Triploid watermelon plants and pollenizers may be planted either in separate rows or interplanted within the same row. The separate-row planting method involves one row of pollenizers followed by two to four rows of triploid plants. Pollenizers were placed every three rows, resulting in a pollenizer-to-triploid ratio of 1:3 (Motsenbocker & Arancibia, 2002) The experiment included the seedless (triploid) hybrids Extazy (Hazera, the Netherlands) and Pekin (Nunhems, the Netherlands), as well as the diploid pollenizer hybrids Premium (Nunhems, the Netherlands), Yummy (LARK SEEDS, USA), and Tatum (Innova Seeds, USA). The size of the accounting plot was 400 m², treatments were randomized complete block design (RCBD) to the experimental plots with four replications. Each replication included six experimental treatments formed by combining two triploid hybrids (Extazy and Pekin) with three pollenizer hybrids (Premium, Yummy, and Tatum). Thus, the experimental design comprised six combinations: Extazy × Premium, Extazy × Yummy, Extazy × Tatum, Pekin × Premium, Pekin × Yummy, and Pekin × Tatum. With four replications, the total number of experimental plots was 24 plots in each year of the study. Within each block, the six treatments were arranged in a randomized order, ensuring randomization of the experimental units. In each year, the experiment was established on an area with similar soil and agroecological characteristics within the same experimental field.

Climatic conditions during the study period

Analysis of data over the three-year period indicates that climatic conditions were characterized by a high degree of interannual variability, manifested in substantial deviations of precipitation and temperature regimes from the long-term average. A clear trend toward warming and uneven precipitation distribution was observed, which is consistent with global climate change patterns.

During 2023–2025, the regional climate was marked by a precipitation deficit and pronounced irregularity in rainfall distribution. Annual precipitation totals were below the long-term norm (527.9 mm in 2023 and 549.3 mm in 2024), with frequent combinations of dry months during critical stages of vegetation (May–June) and short periods of excessive moisture. The temperature regime in all years was anomalously warm, with mean annual temperatures ranging from 10.9 to 11.6 °C, exceeding the long-term average by 2.1–2.8 °C, accompanied by an extension of the high-temperature period and a shift of the thermal season. Relative air humidity decreased during summer, averaging 70–71% annually, which contributed to the development of atmospheric drought and increased evapotranspiration. Overall, the years 2023–2025 can be classified as anomalously warm and reflect a systematic shift of the climatic norm toward more continental and unstable conditions (Yatsenko et al., 2025), (Fig. 1).

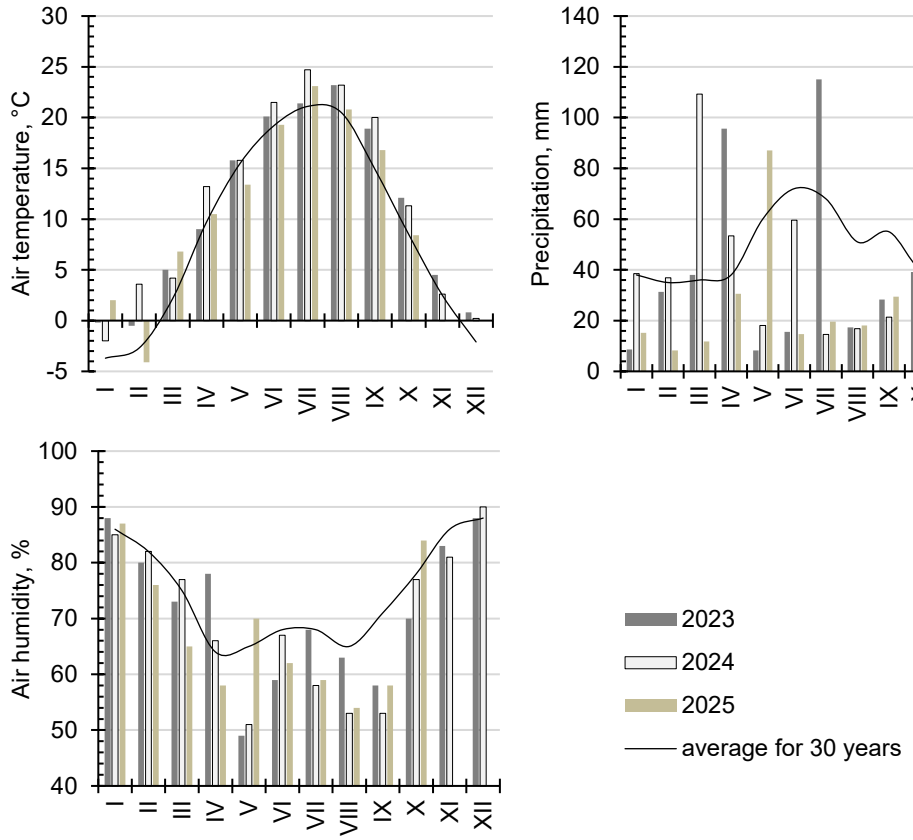


Figure 1. Climate chart for the study period (2023–2025), (data of the Meteorological Station 'Uman').

Yield accounting of watermelon fruits was carried out separately for each experimental treatment and replication. The harvested produce was classified into standard and non-standard categories in accordance with the requirements of DSTU 3805-98 'Fresh food watermelons. Technical specifications' (1998).

The average fruit weight was determined based on weighing results obtained during the first and second harvests.

The content of soluble solids. (°Brix) was determined using visible/near-infrared (vis/NIR) spectroscopy with a portable vis/NIR spectrometer, the Felix Instruments F-750 Produce Quality Meter (Felix Instruments, 2024), operating within a wavelength range of 310–1,100 nm. Prior to each measurement session, the Felix Instruments F-750 Produce Quality Meter was calibrated according to the manufacturer's protocol using dark-current correction and a certified white Spectralon® reference standard. This procedure minimized instrumental drift and compensated for variations in ambient illumination, ensuring the accuracy and repeatability of vis/NIR spectral measurements.

For quality analysis, five representative fruits were collected from each replication (20 fruits per treatment), giving a total sample size of 120 fruits. For sample collection, the fruit was cut longitudinally (from the stem end to the blossom end). A sample of flesh was then excised from the central portion of the fruit, the juice was extracted, and the soluble solids content (°Brix) was determined (Schultheis et al., 2024).

The crude protein content of watermelon fruits was determined by the Kjeldahl method according to AOAC procedures for the determination of total nitrogen in plant materials and protein in fruit products (AOAC 978.04; AOAC 920.152). The method is based on the determination of total organically bound nitrogen, followed by conversion of the nitrogen content to protein. In the official AOAC methods, the Kjeldahl procedure is directly specified for the determination of protein in fruit products. For the analysis, a representative sample of watermelon flesh (20 g) was collected after removing the rind and seeds. The samples were homogenized to a uniform consistency and analyzed in the fresh state. To express the protein content on a fresh-weight basis, the moisture content determined from the same sample was taken into account. A prepared sample weighing 0.5–1.0 g was transferred into a Kjeldahl flask. Concentrated sulfuric acid and a mineralization catalyst were added to the sample. During heating, the organic compounds were decomposed, and the nitrogen present in the organic matter was converted into ammonium salts. After completion of digestion, the solution was cooled and prepared for the distillation step. During distillation, an excess of alkali was added to the digested sample, converting ammonium ions into ammonia. The ammonia was distilled with steam and collected in an appropriate receiving solution. The amount of ammonia was determined titrimetrically based on the volume of standard acid solution required to titrate the distillate. The mass fraction of total nitrogen was calculated from the titration results, taking into account the mass of the test sample and the blank correction. The crude protein content was calculated by multiplying the determined total nitrogen content by a conversion factor of 6.25 (Latimer, 2016).

Free sugar was determined using HPLC, coupled with a refractive index detector using the internal standard methodology (IS, mesostiosis). The sugar composition of watermelon fruits was determined by high-performance liquid chromatography (HPLC). Watermelon flesh without the rind and seeds was used for the analysis. The samples were homogenized to a uniform consistency, after which an analytical portion was taken for the extraction of water-soluble sugars. The prepared sample was extracted with a water–organic solvent mixture of appropriate composition, followed by mixing and centrifugation. The resulting extract was filtered through a membrane filter to remove insoluble particles prior to chromatographic analysis. Standard solutions of sucrose,

glucose, and fructose were used for quantitative determination. Chromatographic separation of the components was performed on a column suitable for the analysis of low-molecular-weight carbohydrates using an appropriate mobile phase. Sucrose, glucose, and fructose were identified based on the retention times of the corresponding standards, while quantitative determination was performed using chromatographic peak areas and calibration curves. For each analytical sample, repeated injections of the prepared extract were performed as technical replicates, whereas samples obtained from different experimental plots were considered independent biological replicates. The results were expressed as a percentage of the fresh watermelon flesh weight (%). This approach enabled the simultaneous determination of the major soluble sugars in watermelon fruits–sucrose, glucose, and fructose–within a single analytical profile. Similar chromatographic approaches are widely used for the quantitative determination of individual sugars in food products and plant materials (Guimarães et al., 2013). For the food and chemical composition, three samples were analysed for each cultivar, and all analyses were performed in three replicates. All results are expressed as g 100^{-1} g FW.

The extraction of free sugars (sucrose, fructose, glucose) was conducted based on the method reported by Yu et al. (2016) and Machado et al. (2020), with some adjustments. Briefly, 1.5 mL of deionized water and 0.15 g of dry powdered edamame were mixed in a 2 mL centrifuge tube. The tube was placed on a tube revolver (Shimadzu, Model Prominence 20A, Japan) and shaken for 2 hat room temperature, followed by centrifugation at 13,500 ×g for 10 min. Afterward, 750 µL acetonitrile was added to 750 µL of the supernatant for purification. The mixture was shaken atroom temperature for 10 min, and then centrifugated at 13,500×g for 10 min. After centrifugation, 750 µL of the supernatant was filtered through a 0.2-µm membrane disc filter into a 1.5-mL HPLC vial and sugar content was determined using high-performance liquid chromatography (HPLC, 1260 Infinity II, Agilent Technologies, Santa Clara, CA, USA) equipped with are fractive index detector (RID). The Luna Omega 3 µm SUGAR column (150×4.6 mm, Phenomenex, Torrance, CA, USA) wasused to separate different sugars. The column temperature wasset at 40 °C with a flow rate of 1.0 mL min^{-1}.

The nutritional value. Proteins, fats, carbohydrates, and ash content were determined by using standard methods described in the procedures of the American Organization of Analytical Chemists (International Organization of International, AOAC International) (Latimer, 2016). The crude fat was determined using a Soxhlet apparatus (Behr R 106 S, Germany) with petroleum ether, according to the AOAC 920.85 methodology (Latimer, 2016). The content of ash was determined by burning at 600°C to constant mass following procedures AOAS 923.03 (Latimer, 2016). The energy was calculated by the formula:

$$Energy, kcal = 4 \times (protein) + 4 \times (carbohydrate) + 9 \times (fat) \quad (1)$$

Statistical analysis

The experimental data were analyzed using analysis of variance (ANOVA) with a combined model for the three years of the study (2023–2025). The analysis was performed to assess the effects of year, triploid (seedless) hybrid, pollenizer, and their interactions on the investigated productivity traits. Since the experiments were conducted using the same experimental design over three years, the data from the

individual years were combined into a single factorial model, which allowed not only the main effects of the factors to be evaluated but also the stability of their expression under different annual conditions.

In the statistical model, year (*Y*), triploid/seedless hybrid (*H*), and pollenizer (*P*) were considered fixed factors. Year was included in the model as a factor with three levels (2023, 2024, and 2025), the triploid/seedless hybrid as a factor with two levels, and the pollenizer as a factor with three levels. Replications were considered as a block effect nested within year [*Rep*(Year)], allowing variation among replications within each year to be accounted for.

The combined analysis of variance was performed according to the following model:

$Yijkl = \mu + Yi + Hj + Pk + (YH)ij + (YP)ik + (HP)jk + (YHP)ijk + Rep(Y)il + \varepsilon ijkl$,

where μ is the overall mean; *Yi* is the effect of year; *Hj* is the effect of the triploid/seedless hybrid; Pk is the effect of the pollenizer; (*YH*)*ij*, (*YP*)ik, and (*HP*)*jk* are the corresponding two-way interactions; (YHP)ijk is the three-way interaction; *Rep*(*Y*)*il* is the effect of replication nested within year; and εijkl is the random error. For each source of variation, degrees of freedom (*df*), sum of squares (*SS*), mean square (*MS*), *F*-statistic, and level of statistical significance (*p*) were determined. Statistical significance was assessed at $\alpha = 0.05$. Values of $p < 0.05$ were considered statistically significant, whereas $p < 0.01$ and $p < 0.001$ were considered highly significant and very highly significant, respectively. Following the detection of a statistically significant factor effect, mean comparisons were performed using Tukey's *HSD* test at $p = 0.05$. When significant interactions involving the year factor were detected, simple effects were additionally evaluated, and the means of the corresponding factor combinations were compared. This approach allowed the nature of changes in the responses of hybrids and pollenizers across the different years of the study to be determined.

RESULTS AND DISCUSSION

The number of fruits per plant was significantly affected by both annual environmental conditions and the genotypic characteristics of the seedless hybrids and the pollenizers used. According to the results of the combined analysis of variance (see Table 5), the effect of year was highly significant ($F_{2.45} = 101.17$; $p < 0.001$), indicating substantial year-to-year variability in this yield component. Among the three years, the highest fruit number was generally recorded in 2024, whereas a decrease was observed in 2025, which was evident in almost all the treatments studied. For example, in the Extazy × Premium combination, the number of fruits per plant was 2.30 in 2023, 2.50 in 2024, and 2.18 in 2025.

The hybrid factor also had a highly significant effect on the number of fruits ($F_{1.45} = 72.12$; $p < 0.001$), as did the pollenizer factor ($F_{2.45} = 54.38$; $p < 0.001$). In addition, the 'year × hybrid' interaction was statistically significant ($F_{2.45} = 8.31$; $p < 0.001$), whereas the 'year × pollenizer' interaction did not reach the significance level of $p < 0.05$ ($p = 0.071$). This indicates that the magnitude of the trait was determined not only by the mean differences among genotypes but also by the differential response of the hybrids to the environmental conditions of individual years.

On average over the three years, the Extazy × Premium combination produced the highest number of fruits per plant (2.33 fruits plant^{-1}), followed by Yummy (2.23 fruits plant^{-1}) and Pekin × Premium (2.13 fruits plant^{-1}). The lowest mean values were observed with Tatum, ranging from 1.92 to 2.06 fruits plant^{-1} depending on the seedless hybrid. A similar trend was observed for the number of fruits per hectare, with mean values ranging from 10,268 to 12,464 fruits ha^{-1}. Thus, the number of fruits represents an important structural component of productivity that, under the conditions of this study, was characterized by substantial year-to-year and genotypic variability (Table 2).

Table 2. Dynamics of fruit number formation in seedless watermelon, 2023–2025

Seedless	Pollenizer	Pcs per plant^{-1}				Pcs ha^{-1}			
		2023	2024	2025	$\overline{X}$	2023	2024	2025	$\overline{X}$
Extazy	Premium	2.30	2.50	2.18	2.33a	12,321	13,393	11,678	12,464a
	Yummy	2.20	2.40	2.08	2.23a	11,786	12,857	11,143	11,928a
	Tatum	2.00	2.20	1.97	2.06b	10,714	11,786	10,553	11,018b
Pekin	Premium	2.20	2.30	1.90	2.13a	11,786	12,321	10,178	11,428a
	Yummy	2.10	2.30	1.80	2.07b	11,250	12,321	9,643	11,071b
	Tatum	2.00	2.00	1.75	1.92b	10,714	10,714	9,375	10,268b

Fruit weight exhibited different patterns of variation between the seedless hybrids and the pollenizers. For seedless fruit weight, highly significant effects of year ($F_{2.45} = 86.55$; $p < 0.001$), hybrid ($F_{1.45} = 37.12$; $p < 0.001$), and pollenizer ($F_{2.45} = 4.53$; $p = 0.016$) were observed. At the same time, the 'year × hybrid' interaction was not statistically significant ($F_{2.45} = 0.08$; $p = 0.922$), indicating a relatively stable response of the hybrids for this trait across the study years. Based on the three-year mean, seedless fruit weight ranged from 4.53 to 4.93 kg. The highest value was recorded for the Pekin × Tatum combination (4.93 kg), whereas the lowest was observed for Extazy × Premium (4.53 kg). For Yummy, the corresponding mean values were 4.57 and 4.85 kg. Thus, genotypic differences in seedless fruit weight were more pronounced than the differences between individual years for the same hybrids. For pollenizer fruit weight, an even more pronounced differentiation was observed: the pollenizer factor had an extremely strong statistical effect ($F_{2.45} = 2{,}893.90$; $p < 0.001$). Based on the three-year means, fruits of Extazy × Premium and Pekin × Premium had weights of approximately 2.92–2.98 kg, whereas for Yummy and Tatum, this trait reached 8.91–9.57 kg. Thus, the differences among pollenizers in fruit weight were very substantial and statistically confirmed (Table 3).

Table 3. Dynamics of fruit weight formation in watermelon, kg, 2023–2025

Seedless	Pollenizer	2023		2024		2025		$\overline{X}$	
		Seedless	Pollenizer	Seedless	Pollenizer	Seedless	Pollenizer	Seedless	Pollenizer
Extazy	Premium	4.71	3.02	4.75	3.19	4.12	2.54	4.53a	2.92c
	Yummy	4.82	8.98	4.68	9.28	4.21	8.46	4.57a	8.91b
	Tatum	4.88	9.71	4.91	9.93	4.27	8.93	4.69a	9.52a
Pekin	Premium	5.13	3.09	5.02	3.27	4.19	2.58	4.78a	2.98c
	Yummy	5.11	9.12	4.86	9.35	4.57	8.37	4.85a	8.95b
	Tatum	4.99	9.71	5.16	10.13	4.63	8.87	4.93a	9.57a

Seedless fruit yield exhibited the greatest degree of year-to-year variation among the traits studied. The effect of year was highly significant ($F_{2.45} = 399.47$; $p < 0.001$), with the highest F-value among all the evaluated traits. This indicates a particularly strong influence of annual environmental conditions on the yield level of seedless hybrids. The annual mean data demonstrated a clear decrease in yield in 2025 compared with 2023–2024 (Table 4).

Table 4. Dynamics of yield formation in watermelon, t ha^{-1}, 2023–2025

Seedless	Pollenizer	Seedless			Pollenizer			Total		
		2023	2024	2025	2023	2024	2025	2023	2024	2025
Extazy	Premium	58.03	63.62	48.12	14.56	15.95	11.88	72.60	79.57	60.00
	Yummy	56.80	60.17	46.91	17.64	19.89	15.86	74.44	80.06	62.77
	Tatum	52.29	57.87	45.06	19.07	19.51	17.54	71.36	77.37	62.61
Pekin	Premium	60.46	61.85	42.65	14.90	16.35	11.98	75.36	78.20	54.63
	Yummy	57.49	58.88	44.07	17.91	20.04	16.44	75.40	78.92	60.51
	Tatum	53.46	55.29	43.41	19.07	19.90	17.74	72.54	75.18	61.15

For example, the yield of the seedless Extazy × Premium combination was 58.03 t ha^{-1} in 2023, 63.62 t ha^{-1} in 2024, and 48.12 t ha^{-1} in 2025. For Yummy, the corresponding values were 56.80, 60.17, and 46.91 t ha^{-1}, whereas for Tatum they were 52.29, 57.87, and 45.06 t ha^{-1}, respectively. A similar year-to-year pattern was observed for Pekin × Premium and its combinations with the pollenizers. The hybrid factor had a statistically significant effect on seedless fruit yield ($F_{1.45} = 8.06$; $p = 0.007$), whereas the main effect of pollenizer was not statistically significant ($F_{2.45} = 2.98$; $p = 0.091$). At the same time, the 'year × hybrid' interaction was highly significant ($F_{2.45} = 10.10$; $p < 0.001$), indicating differential responses of the seedless hybrids to the conditions of individual years. The 'hybrid × pollenizer' interaction was not statistically significant ($p = 0.854$); therefore, a differential effect of specific hybrid–pollenizer combinations on seedless fruit yield was not statistically confirmed. Thus, when evaluating seedless fruit yield, annual environmental conditions and the genotypic characteristics of the hybrid were of primary importance, whereas the choice of pollenizer alone did not result in a statistically significant change in this trait in the combined three-year analysis.

Pollenizer fruit yield also varied significantly depending on year and genotype. The effect of year was highly significant ($F_{2.45} = 155.65$; $p < 0.001$), while the pollenizer factor had a very strong statistical effect ($F_{2.45} = 317.58$; $p < 0.001$). In addition, the 'year × pollenizer' interaction was statistically significant ($F_{4.45} = 7.47$; $p < 0.001$), indicating that the yield of individual pollenizers changed differently depending on the year.

According to the three-year data, the highest pollenizer fruit yields were recorded for Tatum, ranging from 19.29 to 19.49 t ha^{-1}, whereas for Yummy they were approximately 18.76–18.98 t ha^{-1}, and for Extazy × Premium and Pekin × Premium they were only 15.26–16.62 t ha^{-1} (Fig. 2). The differences among pollenizers were statistically confirmed by the significant main effect of the pollenizer factor ($F = 317.58$; $p < 0.001$) (see Table 5). Notably, the 'hybrid × pollenizer' interaction for pollenizer fruit yield was not statistically significant ($F_{2.45} = 0.07$; $p = 0.937$). Therefore, there is no statistical basis for claiming that the same pollenizer produced a fundamentally

different level of its own yield depending on the particular seedless hybrid. The observed differences should primarily be interpreted in terms of the main effect of the pollenizer factor and its interaction with year.

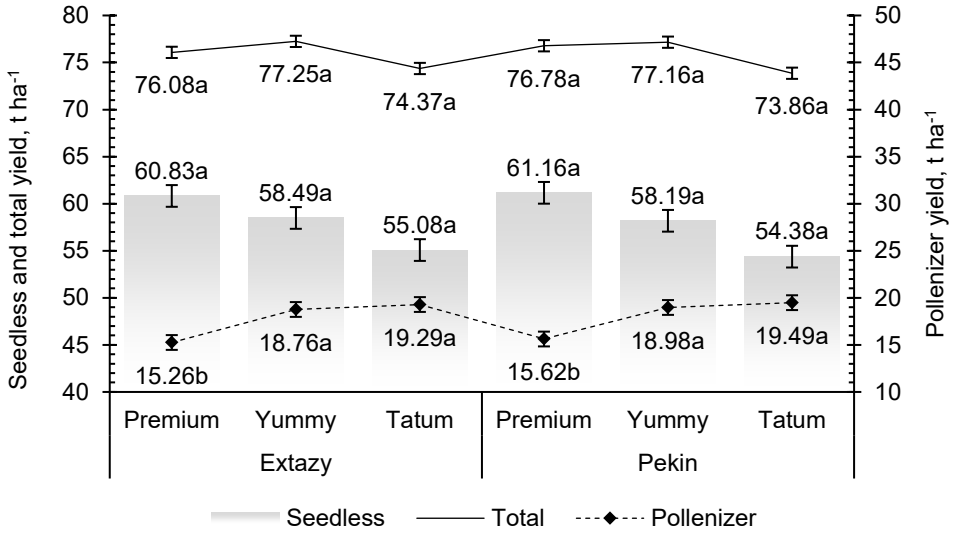


Figure 2. Average yield of watermelon, t ha^{-1}, 2023–2025.

The combined analysis of variance for 2023–2025 (Table 5) showed that year had a statistically significant effect on all the traits studied ($p < 0.001$), indicating a substantial dependence of the productivity of the genotypes and the pollination system on annual environmental conditions. The strongest effect of year was observed for seedless hybrid yield ($F_{2.45} = 399.47$; $p < 0.001$) and the yield of the 'pollenizer × seedless hybrid' system ($F_{2.45} = 239.38$; $p < 0.001$).

The hybrid factor had a significant effect on the number of fruits, the number of fruits per unit area, seedless fruit weight, and seedless hybrid yield. However, its effects on pollenizer fruit weight, pollenizer yield, and total system yield were not statistically significant ($p > 0.05$).

The pollenizer factor had a significant effect on all the traits studied, except for the corresponding interactions, where the effect remained significant at the $p < 0.05$ level. Particularly strong effects were observed for pollenizer fruit weight ($F_{2.45} = 2{,}893.90$; $p < 0.001$) and pollenizer yield ($F_{2.45} = 317.58$; $p < 0.001$).

The statistically significant 'year × hybrid' interaction for the number of fruits, the number of fruits per unit area, seedless hybrid yield, and total system yield indicates that the response of the hybrids depended on the conditions of the particular year. A significant 'year × pollenizer' interaction was observed for seedless fruit weight, seedless hybrid yield, pollenizer yield, and total system yield.

Therefore, evaluating productivity solely based on mean values across years is insufficient, and the detected interactions confirm the need to analyze the responses of the treatments in each individual year.

Table 5. Results of the combined analysis of variance of the studied traits for 2023–2025

Source of variation	Number of fruits, fruits/plant	Number of fruits, thousand fruits ha^{-1}	Seedless fruit weight, kg	Pollenizer fruit weight, kg	Seedless hybrid yield, t ha^{-1}	Pollenizer yield, t ha^{-1}	System yield, t ha^{-1}
Year	**$F_{2.45}$ = 101.17; p < 0.001**	**$F_{2.45}$ = 92.94; p < 0.001**	**$F_{2.45}$ = 86.55; p < 0.001**	**$F_{2.45}$ = 46.95; p < 0.001**	**$F_{2.45}$ = 399.47; p < 0.001**	**$F_{2.45}$ = 155.65; p < 0.001**	**$F_{2.45}$ = 239.38; p < 0.001**
Hybrid	**$F_{1.45}$ = 72.12; p < 0.001**	**$F_{1.45}$ = 66.26; p < 0.001**	**$F_{1.45}$ = 37.12; p < 0.001**	$F_{1.45}$ = 0.41; p = 0.526	**$F_{1.45}$ = 8.06; p = 0.007**	$F_{1.45}$ = 2.98; p = 0.091	$F_{1.45}$ = 2.01; p = 0.163
Pollenizer	**$F_{2.45}$ = 54.38; p < 0.001**	**$F_{2.45}$ = 49.96; p < 0.001**	**$F_{2.45}$ = 4.53; p = 0.016**	**$F_{2.45}$ = 2,893.90; p < 0.001**	**$F_{2.45}$ = 36.02; p < 0.001**	**$F_{2.45}$ = 317.58; p < 0.001**	**$F_{2.45}$ = 3.57; p = 0.036**
Year × Hybrid	**$F_{2.45}$ = 8.31; p < 0.001**	**F$_{2.45}$ = 7,64; p = 0.001**	F$_{2.45}$ = 0.08; p = 0.922	$F_{2.45}$ = 0.34; p = 0.716	**$F_{2.45}$ = 10.10; p < 0.001**	$F_{2.45}$ = 0.05; p = 0.955	**$F_{2.45}$ = 3.93; p = 0.027**
Year × Pollenizer	$F_{4.45}$ = 2.33; p = 0.071	$F_{4.45}$ = 2.14; p = 0.092	**$F_{4.45}$ = 3.05; p = 0.026**	$F_{4.45}$ = 1.01; p = 0.414	**$F_{4.45}$ = 5.24; p = 0.001**	**$F_{4.45}$ = 7.47; p < 0.001**	**$F_{4.45}$ = 3.65; p = 0.012**
Hybrid × Pollenizer	$F_{2.45}$ = 0.65; p = 0.529	$F_{2.45}$ = 0.59; p = 0.557	$F_{2.45}$ = 0.07; p = 0.937	$F_{2.45}$ = 0.01; p = 0.992	$F_{2.45}$ = 0.16; p = 0.854	$F_{2.45}$ = 0.07; p = 0.937	$F_{2.45}$ = 0.06; p = 0.943
Year × Hybrid × Pollenizer	$F_{4.45}$ = 0.84; p = 0.505	$F_{4.45}$ = 0.77; p = 0.548	$F_{4.45}$ = 1.67; p = 0.173	$F_{4.45}$ = 0.13; p = 0.971	$F_{4.45}$ = 1.35; p = 0.267	$F_{4.45}$ = 0.23; p = 0.918	$F_{4.45}$ = 0.61; p = 0.659
Replication (Year)	$F_{9.45}$ = 0.96; p = 0.483	$F_{9.45}$ = 0.83; p = 0.596	$F_{9.45}$ = 0.79; p = 0.625	$F_{9.45}$ = 0.51; p = 0.860	$F_{9.45}$ = 1.19; p = 0.323	$F_{9.45}$ = 1.32; p = 0.252	$F_{9.45}$ = 0.36; p = 0.948
Error	df = 45	df = 45	df = 45	df = 45	df = 45	df = 45	df = 45

Note. F – Fisher's F-statistic; df – degrees of freedom; p – level of statistical significance. Bold indicates statistically significant effects at $p < 0.05$. 'Replication (Year)' refers to replications nested within year. Hybrid and pollenizer were treated as fixed factors; year was also considered a fixed factor within the scope of this study.

At the same time, the 'hybrid × pollenizer' interaction and the three-way 'year × hybrid × pollenizer' interaction were not statistically significant for any of the traits studied ($p > 0.05$). This indicates the absence of a statistically confirmed change in the combined interaction between hybrid and pollenizer depending on the year. The effect of replications nested within year was also not statistically significant for any trait ($p > 0.05$), indicating relatively low block variation compared with the variation attributable to the factors under study.

Soluble solids content. In the fruits of the triploid hybrid Extazy, the soluble solids content in combination with the Premium pollenizer was 11.29 °Brix in 2023, 12.35 °Brix in 2024, and 11.57 °Brix in 2025, whereas the corresponding values in the pollenizer fruits were 10.73, 11.72, and 11.15 °Brix, respectively. When Yummy was used, the values for Extazy were 11.28, 12.31, and 11.58 °Brix, respectively, while those for the pollenizer were 10.46, 11.53, and 10.94 °Brix. In the Tatum treatment, the soluble solids content in Extazy fruits was 11.26, 12.33, and 11.55 °Brix, whereas in the pollenizer fruits it was 10.67, 11.82, and 11.08 °Brix, respectively. Thus, over the three years of the study, Extazy was characterized by a soluble solids range of 11.26–12.35 °Brix, with the highest values recorded in 2024.

In the fruits of the Pekin hybrid, when Premium was used as the pollenizer, the soluble solids content was 11.09 °Brix in 2023, 12.09 °Brix in 2024, and 11.41 °Brix in 2025, whereas the corresponding values in the pollenizer fruits were 10.75, 11.70, and 11.16 °Brix. When Pekin was combined with Yummy, the soluble solids content in the

hybrid fruits was 11.09, 12.07, and 11.39 °Brix, respectively, while in the pollenizer fruits it was 10.48, 11.51, and 10.92 °Brix. When Tatum was used, the corresponding values for Pekin were 11.11, 12.09, and 11.43 °Brix, whereas those for the pollenizer were 10.70, 11.83, and 11.10 °Brix, respectively. Overall, the soluble solids content in Pekin ranged from 11.09 to 12.09 °Brix, with the highest values also recorded in 2024 (Table 6).

Table 6. Dynamics of soluble solids content in the fruits of seedless (triploid) watermelon hybrids when using different pollenizer hybrids, °Brix, %, 2023–2025

Seedless	Pollenizer	2023		2024		2025	
		Seedless	Pollenizer	Seedless	Pollenizer	Seedless	Pollenizer
Extazy	Premium	11.29	10.73	12.35	11.72	11.57	11.15
	Yummy	11.28	10.46	12.31	11.53	11.58	10.94
	Tatum	11.26	10.67	12.33	11.82	11.55	11.08
Pekin	Premium	11.09	10.75	12.09	11.70	11.41	11.16
	Yummy	11.09	10.48	12.07	11.51	11.39	10.92
	Tatum	11.11	10.70	12.09	11.83	11.43	11.10

The annual mean values presented in Fig. 3 indicate a similar level of soluble solids content in Extazy and Pekin fruits across the different pollenizer combinations. For Extazy, the mean values ranged from approximately 11.71 to 11.74 °Brix, whereas for Pekin, they ranged from approximately 11.52 to 11.54 °Brix. For the pollenizer fruits, the mean values were approximately 10.97–11.21 °Brix across the respective combinations.

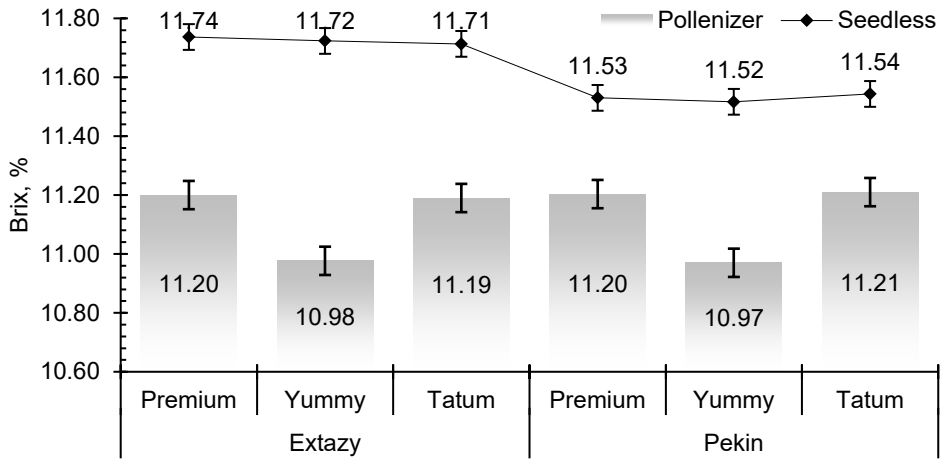


Figure 3. Average soluble solids content in the fruits of seedless (triploid) watermelon hybrids when using different pollenizer hybrids, °Brix, %, 2023–2025.

The sucrose content in Extazy fruits was 2.902% when Premium was used, 2.931% with Yummy, and 3.386% with Tatum. In Pekin fruits, this parameter was 3.651% with Premium, 3.739% with Yummy, and 3,.986% with Tatum. Thus, the sucrose content across the studied combinations ranged from 2.902% to 3.986%, with the highest value recorded in Pekin fruits in combination with the Tatum pollenizer.

The glucose content in Extazy fruits was 4.221% with Premium, 4.220% with Yummy, and 3.853% with Tatum. For Pekin, the corresponding values were 3.878%, 4.149%, and 3.973%, respectively. Thus, the overall glucose content ranged from 3.853% to 4.221%, with the highest value recorded for the Extazy × Premium combination and the lowest for Extazy × Tatum.

The fructose content in Extazy fruits was 4.613% with Premium, 4.571% with Yummy, and 4.475% with Tatum. In Pekin fruits, the corresponding values were 4.001%, 3.629%, and 3.584%, respectively. Thus, fructose content ranged from 3.584% to 4.613%, with the highest value recorded for the Extazy × Premium combination and the lowest for Pekin × Tatum (Table 7).

Table 7. Sugar composition ratio in the fruits of seedless (triploid) watermelon hybrids when using different pollenizer hybrids, %, 2023–2025

Seedless	Pollenizer	Sucrose	Glucose	Fructose
Extazy	Premium	2.902	4.221	4.613
	Yummy	2.931	4.220	4.571
	Tatum	3.386	3.853	4.475
Pekin	Premium	3.651	3.878	4.001
	Yummy	3.739	4.149	3.629
	Tatum	3.986	3.973	3.584

The protein content in Extazy fruits was 0.620% with Premium, 0.550% with Yummy, and 0.550% with Tatum. In the fruits of the corresponding pollenizers, the values were 0.650%, 0.570%, and 0.570%, respectively. For Pekin, the protein content was 0.600% with Premium, 0.480% with Yummy, and 0.450% with Tatum, whereas the corresponding values in the pollenizer fruits were the same as those reported for the other combinations – 0.650%, 0.570%, and 0.570%, respectively. Thus, among the fruits of the triploid hybrids, the protein content ranged from 0.450% to 0.620%, whereas in the fruits of the diploid pollenizers, it ranged from 0.570% to 0.650%.

The fat content in Extazy fruits was 0.052% with Premium, 0.057% with Yummy, and 0.054% with Tatum. For Pekin, the corresponding values were 0.073%, 0.086%, and 0.081%, respectively. In the pollenizer fruits, the fat content ranged from 0.090% to 0.103%. Thus, the studied triploid hybrids were characterized by a fat content ranging from 0.052% to 0.086%, whereas in the pollenizer fruits it ranged from 0.090% to 0.103%.

The carbohydrate content in Extazy fruits was 6.02% with Premium, 4.57% with Yummy, and 5.05% with Tatum. In the corresponding pollenizer fruits, the values were 6.32%, 2.12%, and 2.14%, respectively. For Pekin, the carbohydrate content was 5.75% with Premium, 4.04% with Yummy, and 4.22% with Tatum, whereas in the pollenizer fruits the corresponding values were 6.32%, 2.12%, and 2.14%, respectively. Thus, in the studied fruits of the triploid hybrids, the overall carbohydrate content ranged from 4.04% to 6.02%, whereas in the pollenizer fruits it ranged from 2.12% to 6.32%.

The energy value of Extazy fruits was 27.03 kcal per 100 g fresh weight with Premium, 20.99 kcal with Yummy, and 22.89 kcal with Tatum. In the fruits of the corresponding pollenizers, the energy values were 28.69, 11.69, and 11.75 kcal per 100 g fresh weight, respectively. For Pekin, the energy value was 26.06 kcal with Premium, 18.85 kcal with Yummy, and 19.41 kcal per 100 g fresh weight with Tatum, whereas the corresponding values for the pollenizers were 28.69, 11.69, and 11.75 kcal per 100 g fresh weight, respectively. Thus, among the triploid hybrids, the energy value ranged from 18.85 to 27.03 kcal per 100 g fresh weight, whereas among the pollenizer fruits it ranged from 11.69 to 28.69 kcal per 100 g fresh weight (Table 8).

Table 8. Nutritional value parameters of triploid (seedless) watermelon fruits and diploid pollenizer fruits, 2023–2025

Seedless	Pollenizer	Protein, %		Fat, %		Carbohidrates, %		Energy (kcal 100 g f. w.$^{-1}$)	
		Seedless	Pollenizer	Seedless	Pollenizer	Seedless	Pollenizer	Seedless	Pollenizer
Extazy	Premium	0.620	0.650	0.052	0.090	6.02	6.32	27.03	28.69
	Yummy	0.550	0.570	0.057	0.103	4.57	2.12	20.99	11.69
	Tatum	0.550	0.570	0.054	0.101	5.05	2.14	22.89	11.75
Pekin	Premium	0.600	0.650	0.073	0.090	5.75	6.32	26.06	28.69
	Yummy	0.480	0.570	0.086	0.103	4.04	2.12	18.85	11.69
	Tatum	0.450	0.570	0.081	0.101	4.22	2.14	19.41	11.75

Overall, the data presented characterize the chemical and nutritional profile of the fruits of the triploid hybrids Extazy and Pekin and the diploid pollenizers Premium, Yummy, and Tatum. In terms of soluble solids content, the fruits of the triploid hybrids were predominantly within the range of 11–12 °Brix, whereas the levels of sucrose, glucose, and fructose resulted in different proportions of the individual components of the sugar profile. The nutritional characteristics of the fruits included protein, fat, carbohydrate content, and energy value, with these parameters varying depending on the hybrid studied and its combination with the pollenizer.

While previous studies have primarily optimized triploid watermelon production through adjustments in plant density and planting arrangement, our findings demonstrate that the selection of a suitable diploid pollenizer should also be regarded as a critical technological component, as it determines not only seedless fruit yield but also the overall biological and production efficiency of the cultivation system. Motsenbocker & Arancibia (2002) also demonstrated genotype-specific responses of triploid watermelon hybrids to production practices. Likewise, the present study revealed that the response to pollenizer genotype depended on the recipient triploid hybrid, indicating that genotype × management interactions play an important role in determining productivity and fruit quality. Whereas Motsenbocker & Arancibia (2002) emphasized the optimization of plant spacing to balance fruit number and fruit size, the present study indicates that optimization of pollenizer genotype should also be considered an essential component of triploid watermelon production technology because it directly influences seedless fruit yield and may additionally affect fruit quality.

The yield of triploid hybrids in the present study ranged from 54.38 to 61.16 t ha^{-1}, which is consistent with the values reported by Cushman et al. (2003), Boyhan et al. (2019), Guan et al. (2019), and Kumari (2025), confirming the high productive potential of modern seedless watermelon hybrids. Similar to our findings, long-term cultivar evaluations conducted in Indiana demonstrated substantial interannual variation in productivity, with marketable yield being strongly influenced by environmental conditions. In particular, exceptionally high precipitation during the 2019 growing season promoted the development of *Phytophthora* fruit rot and *Fusarium* wilt, resulting in a marked reduction in marketable yield compared with previous seasons. These observations support our results, in which the significantly lower productivity recorded in 2025 also reflected the considerable influence of annual weather conditions on the realization of the genetic yield potential of triploid hybrids. Similar variability among modern triploid cultivars has also been reported by Schultheis et al. (2024), who

demonstrated substantial differences in marketable yield among commercially available seedless watermelon hybrids grown under identical production conditions. These observations further support the importance of genotype selection for maximizing productivity. Our findings are consistent with the early cultivar evaluations reported by Schultheis et al. (2001), who demonstrated considerable variation among commercial triploid watermelon cultivars in marketable yield, fruit weight, and soluble solids content under identical production conditions. These observations indicate that genotype remains one of the principal factors determining productivity and fruit quality, whereas environmental conditions primarily influence the extent to which this genetic potential is expressed. It is particularly important to note that Schultheis et al. (2001) evaluated only triploid watermelon hybrids, whereas the present study is the first to provide a comprehensive assessment of the *triploid hybrid* × *diploid pollenizer* system. This assessment included pollenizer productivity, seedless fruit yield, total production system productivity, and the potential influence of the pollen donor on the fruit quality of seedless watermelon. These aspects represent a key scientific distinction and the principal novelty of the present study.

Our results demonstrated that 2024 produced the highest marketable yield, whereas the average fruit weight followed the opposite trend. A similar inverse relationship between fruit number and individual fruit weight has been reported in previous watermelon cultivar evaluations, where seasons characterized by favorable conditions for fruit set generally resulted in increased fruit numbers but reduced average fruit mass. In the Indiana trials, considerable differences among years were likewise observed in fruit size distribution and marketable yield, indicating that environmental conditions during flowering and fruit development largely determine sink-source relationships within watermelon plants. The significantly smaller fruits observed in our experiment during 2024 are therefore likely attributable to elevated temperatures during the fruit-setting period, which promoted greater fruit set and consequently increased competition among developing fruits for assimilates.

In the present study, the highest marketable yield was obtained in 2024, when the average fruit weight was the lowest. Thus, the increase in productivity was primarily associated with the formation of a greater number of fruits rather than with an increase in individual fruit weight, which is in full agreement with the findings of Sanders et al. (1999), who demonstrated that marketable watermelon yield depends mainly on the number of fruits produced per unit area. The reduction in average fruit weight observed during the highest-yielding season was most likely the result of more intensive fruit set and increased competition among developing fruits for assimilates, consistent with the physiological patterns described by Sanders et al. (1999). Furthermore, whereas Sanders et al. (1999) demonstrated the decisive role of plant density and planting arrangement in maximizing watermelon productivity, the results of the present study indicate that, in triploid watermelon production, the selection of an appropriate diploid pollenizer represents an equally important technological component, influencing not only the yield of seedless fruits but also the overall productivity and biological efficiency of the production system.

Fruit quality represents another critical component of seedless watermelon production. According to the quality standards of the United States Department of Agriculture, fruits containing more than 10% soluble solids are classified as having very

good internal quality (USDA Agricultural Marketing Service, 2021). All pollenizer × triploid combinations evaluated in the present study exceeded this threshold, with average SSC values ranging from 11.09% to 11.74%. Comparable SSC values have also been reported in cultivar evaluations conducted in Indiana, where commercially important triploid cultivars consistently produced fruits exceeding 11% soluble solids despite considerable variation in yield among years. These observations indicate that fruit sweetness is relatively stable genetically, although environmental conditions may substantially influence its final expression. Cushman et al. (2003) likewise reported significant differences in soluble solids concentration among triploid cultivars, indicating that fruit sweetness is strongly genotype-dependent. However, unlike their study, which evaluated only triploid cultivars, our results indicate that pollenizer genotype may additionally modify soluble solids accumulation in certain triploid hybrids. Unlike Cushman et al. (2003), who evaluated only the agronomic performance and fruit quality of triploid watermelon cultivars, the present study additionally investigated the contribution of diploid pollenizer genotype to seedless fruit yield, total production system productivity, and soluble solids accumulation. Consequently, our results extend previous cultivar evaluations by demonstrating that pollenizer selection should be considered an integral component of triploid watermelon production technology. Our results are consistent with those of Sultana et al. (2024), who demonstrated substantial genotypic variability in soluble solids concentration and other nutritional characteristics of watermelon fruits. Similarly, the present study confirmed that fruit sweetness is primarily determined by the genetic characteristics of the triploid hybrid. However, unlike their work, which evaluated only genotype effects, our results further indicate that pollenizer genotype may modify soluble solids accumulation in certain triploid hybrids, suggesting that pollenizer selection can contribute not only to fruit set but also to fruit quality improvement.

Unlike the findings of Fiacchino & Walters (2000, 2003), who concluded that pollenizer genotype had little effect on soluble solids accumulation, our results indicate that this response depends on the genotype of the triploid hybrid. In particular, the hybrid Extazy exhibited a significantly higher soluble solids content when pollinated by the Premium pollenizer, suggesting a potential influence of the pollen donor genotype on the biochemical characteristics of developing fruits. Although the physiological mechanisms underlying this phenomenon remain insufficiently understood, the present findings indicate that pollenizer selection may affect not only fruit set but also certain fruit quality attributes. Unlike recent cultivar evaluation studies, including the NC State triploid watermelon trial (Schultheis et al., 2024), which primarily focused on the agronomic performance and fruit quality of commercial triploid cultivars, the present study additionally evaluated the biological efficiency of different pollenizer genotypes, their contribution to total system productivity, and their potential influence on soluble solids accumulation in seedless fruits.

The role of pollenizers in seedless watermelon production has traditionally been evaluated according to their ability to ensure adequate pollination of triploid plants. Freeman et al. (2007) emphasized that productive pollenizer cultivars could improve the economic efficiency of seedless watermelon production because their fruits may also be

marketed. Our results partially support this concept. The pollenizers Yummy and Tatum demonstrated significantly greater individual productivity than Premium, contributing to higher total system productivity.

The present study therefore extends previous research by demonstrating that the evaluation of pollenizers should be based on an integrated assessment of seedless fruit yield, pollenizer productivity, total production system output, and fruit quality rather than on a single agronomic trait. This comprehensive approach is particularly relevant under conditions of increasing climatic variability, where genotype × environment × pollenizer interactions become increasingly important for maintaining stable production.

Despite significant advances in seedless watermelon production technology, relatively few studies published during the last five years have simultaneously evaluated pollenizer genotype, triploid hybrid response, fruit quality, and overall production system efficiency under field conditions. Most available studies have focused either on cultivar evaluation or on general production practices, whereas comprehensive investigations of pollenizer–triploid interactions remain scarce. Consequently, the present work contributes new information on optimizing pollenizer selection under the agroecological conditions of the Right-Bank Forest-Steppe of Ukraine and provides a scientific basis for improving seedless watermelon production technologies under ongoing climate change.

CONCLUSIONS

The integration of the results obtained over three years of research demonstrated that the productivity, fruit quality, and production stability of seedless (triploid) watermelon hybrids were determined by both the genotype of the triploid hybrid and the biological characteristics of the diploid pollenizer. Among the pollenizers studied, Premium provided higher yields of triploid hybrids; however, this difference was not statistically confirmed in the experiment, whereas Yummy and Tatum, despite their higher individual productivity and larger fruit size, generally provided lower yields of seedless fruits.

Fruit weight and soluble solids concentration were affected primarily by the genotype of the triploid hybrid and exhibited relatively high stability across pollenizer treatments. Nevertheless, the response of soluble solids accumulation differed between hybrids, suggesting that the influence of pollenizer genotype on fruit quality may depend on the genetic background of the recipient triploid hybrid. In particular, the Extazy hybrid tended to accumulate higher concentrations of soluble solids when pollinated by Premium, indicating a possible genotype-specific pollenizer effect that requires further physiological investigation.

Overall, the results suggest that optimization of pollenizer selection represents an important component of triploid watermelon production technology. Under the agroecological conditions of the Right-Bank Forest-Steppe of Ukraine, the Premium pollenizer provided the most favorable combination of seedless fruit yield and fruit quality, although additional multi-location studies are required to confirm the stability of these relationships under a wider range of environmental conditions.

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