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COMPARATIVE EVALUATION OF EGGPLANT PLANT ESTABLISHMENT METHODS: CASE STUDY ON MIRVAL AND BLACK PEARL HYBRIDS

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Abstract

Efficient cultivation of eggplants is gaining renewed importance in sustainable farming strategies, as rising demand forces producers to manage land, water, and labour with a degree of precision that earlier systems seldom required. Given the crop's thermophilic nature, its performance depends strongly on the establishment method, either open-field planting or cultivation in unheated solar tunnels, an agronomic choice that has implications for both productivity and longer-term resource sustainability. Between 2019 and 2021, at the "V. Adamachi" Experimental Station, two hybrids, Mirval F1 and Black Pearl F1, were grown under two systems. Transplanted seedlings were maintained under relatively uniform irrigation and fertilisation regimes, allowing analysis of the factors that shape yield formation and resource-use efficiency, even though minor seasonal variations still occurred in practice. The comparative results indicated a consistent advantage for the protected environment: yields increased by approximately 50–70% relative to open-field production, largely due to a higher fruit load per plant and, to a smaller extent, slightly greater fruit mass. The hybrids displayed distinct adaptive patterns as well. Mirval F1 reached commercial maturity earlier and set more fruits per plant, whereas Black Pearl F1 produced larger fruits and expressed its yield potential most fully under the moderated microclimate of the tunnel structure.

Key words: *Eggplant (Solanum melongena L.), high tunnel cultivation, open-field production, yield components, sustainable vegetable systems.*

INTRODUCTION

Eggplant (*Solanum melongena* L.) has gradually assumed a prominent role among vegetable species, not only because of its nutritional profile and the concentration of antioxidant compounds it contains, but also due to the way it seems to integrate into culinary traditions (Gürbüz et al., 2018; Koley et al., 2019; Salamatullah et al., 2021; Silva et al., 2020). Currently, the eggplant crop occupies roughly 1.8 million hectares worldwide, from the milder Mediterranean zones to humid tropical regions, and even in places that challenge the species beyond its comfortable thermal limits (Rasouli et al., 2023).

Eggplant now ranks, according to Rasouli et al. (2023), in fourth place among the top greenhouse-grown vegetables. However, the exact position tends to fluctuate depending on the dataset consulted, and this variation appears linked to the crop's marked sensitivity to stabilized, moderated environments (Shımıra and Taşkın, 2022).

Unheated greenhouses and simple plastic tunnels enable growers to extend the season beyond what open fields usually permit, while also adjusting the microclimate in ways that outdoor systems simply cannot (Sharaf-Eldin et al., 2023). These advantages have become more salient as weather patterns show an increasingly erratic behaviour from one year to the next, pushing agriculture toward forms of "sustainable intensification" that are not always easy to implement (Bell et al., 2024).

Despite these benefits, a significant number of farmers continue to rely on open-field production, partly due to familiarity and partly because the upfront costs remain far lower (Gan et al., 2022). This method demands fewer technological inputs, yet exposes the crop to abrupt temperature declines, uneven rainfall, and a range of pest pressures. Each of these factors may curtail, at times quite severely, the

level of productivity that eggplant can achieve when grown under more buffered conditions.

Selecting an appropriate cultivation system has become a rather persistent challenge in sustainable agriculture, as producers must attain high yields while avoiding the gradual depletion of the resources on which the system relies (Khan et al., 2021). In temperate continental regions, the NE part of Romania offers a familiar example: summers generally supply adequate heat, yet the frost-free period remains unexpectedly short (Rothacher, 2021). This compressed window limits the growth trajectory of thermophilic crops such as eggplant when they are placed directly into open soil.

Recent research reinforces the advantages of protected systems. For example, Shaik et al. (2023) showed that organic eggplants cultivated in tunnel greenhouses produced roughly 84% more than those in the open field, largely due to improved fruit set and a modest increase in average fruit mass (Ciubotarita et al., 2022). Resource management can be notably improved, particularly in semi-arid regions. In Egypt, for example, Fan et al. (2023) have shown that greenhouse-grown eggplants required nearly 90% less irrigation than their field counterparts, while net profit increased by more than 80%, even if seasonal costs did not remain fully constant, as so often happens.

Taken together, these observations indicate that protected cultivation offers considerable potential for improving both economic outputs and resource efficiency, especially in areas where open-field production is repeatedly pressured by climatic instability.

The benefits of protected cultivation for eggplant are often discussed, but its performance compared with open-field systems is not well understood, particularly in Romania's specific climate and with recent hybrids. Existing evidence is often limited, lacking comprehendsive multi-year data to accurately compare yield and quality between the two methods, especially regarding economic sustainability.

Excessive heat in greenhouses can hinder production without proper ventilation, and a lack of natural pollinators may negatively impact fruit set (Abbas et al., 2025). One study found that a controlled greenhouse yielded smaller harvests than nearby field plots due to inadequate pollination and low light penetration (Dingley et al., 2022). This raises the unresolved question of how the advantages of protected cultivation translate into actual field-level gains, considering the differing responses of eggplant hybrids to contrasting environments.

This study aimed to clarify ambiguities by comparing eggplant grown in a tunnel versus open-field conditions, focusing on total yield, fruit number per plant, and average fruit weight. The hybrids selected, Mirval F1 and Black Pearl F1, are part of a more recent cohort of high-performance genetic lines. Both are marketed for protected and outdoor cultivation, though their profiles differ: Mirval F1 is generally classified as very early and relatively stable across environments (Abdelnaby et al., 2024), whereas Black Pearl F1 is usually recommended for open-field production (Gaccione et al., 2023), producing medium-to-large fruits with a teardrop shape and a high degree of uniformity, even if its performance shifts a bit from year to year.

MATERIALS AND METHODS

The research was carried out from 2020 to 2021 in the "V. Adamachi" Research and Training Station Iași, Romania. The area is characterised by a temperate-continental climate; summers tend to be warm, with July means around 21-22°C, although a fair number of days rise well above 30°C. Rainfall occurs irregularly and, rather often, at moments that complicate open-field management, influencing crop performance more than producers usually care to admit (Istrate et al., 2023).

Each experimental cycle began in early spring and continued into autumn, with harvests collected through summer and the early part of autumn. The same design was implemented during 2020 and 2021, allowing the datasets to remain comparable and, at least in principle, to provide more dependable trends, even if small seasonal shifts did appear from one year to the next.

For ease of interpretation, Table 1 groups the principal experimental factors and indicates how each was applied in practice, including brief notes from field observations. Table 1 summarises the principal elements of the experimental design, indicating how each factor was defined and applied across the two cultivation systems, showing how the hybrids could

diverge in their behaviour, and allowing the yield outcomes to be read against the broader agronomic tendencies that emerged, even if a section of year-to-year drift was, unavoidably, still present.

The greenhouse used in the trial was a straightforward, unheated tunnel covered with PE film, equipped with manually operated side vents, and occupying roughly 250 m². The open-field plots assigned to the unprotected variant were situated only a short distance away, on the same well-drained cambic chernozem, ensuring that soil variability would not interfere with comparisons.

Table 1. Overview of the experimental framework

Factor	Practical meaning	Examples from the study
Cultivation method	Compares crop performance in a protected environment and in open field	Solar greenhouse setting; conventional field plots
Hybrid used	Two modern hybrids assessed for their contrasting traits:	Mirval F1, Black Pearl F1
Seedling production	Seedlings grown in trays with sterile substrate under controlled temperature	Transplanting performed once plants had 5 to 6 true leaves
Planting calendar	Transplant dates adapted to climatic risks in each system	Greenhouse: mid to late April; Field: early May
Phenological advantage in greenhouse	Plants start growing earlier under protection than outdoors	Roughly a three-week advance in early development
Mirval F1 traits	Very early type, good adaptability, and stable yield potential	Earlier fruit initiation and higher fruit number
Black Pearl F1 traits	Vigorous hybrid producing larger fruits, performs strongly in open field	Higher fruit mass and more robust vegetative growth
Expected hybrid differences	Anticipated variability in response to environmental conditions	Mirval favoured by field timing; Black Pearl enhanced in greenhouse

Soil preparation followed the standard routine: autumn ploughing, disking, and bed formation. Inside the tunnel, the beds ended up somewhat wider to make slightly better use of the protected surface, although planting density was kept the same in both systems, at least in theory; small deviations do slip in during fieldwork.

Plants were spaced 70 cm between rows and 40 cm on the row, a configuration equivalent to approximately 35,000 plants/ha. Each experimental plot, corresponding to one A×B combination, contained four rows with ten plants per row, yielding forty plants over an effective surface of a little under 11 m².

The study employed a two-factor randomized block arrangement with three replications. Factor A, the cultivation environment, could not be fully randomized, since each block necessarily included one greenhouse section and a corresponding open-field section positioned nearby.

Overall crop management

Crop management was maintained as closely as practicable between the two cultivation systems, since the intention was for any differences to arise from the experimental factors rather than from extra technological variability. Prior to planting, the soil received well-decomposed farmyard manure-about 30 t/ha, incorporated in autumn to provide a reasonably uniform nutrient background. At transplanting, a small starter dose was placed directly in each planting hole, roughly 5 g of a 14-14-14 NPK formulation, a routine measure many growers use to help seedlings settle a bit quicker.

Throughout the vegetation period, both systems followed the same top-dressing schedule. Ammonium nitrate was applied three weeks after transplanting at around 50 kg/ha, followed by two monthly applications of a 20-20-20 fertilizer, close to 5 kg/ha each time. Irrigation relied on drip lines, one per row, in both the tunnel and the open field, all connected to the same water source so that no hidden discrepancies would creep in unnoticed. Under typical weather conditions, watering occurred twice weekly; during hotter intervals, it increased to three times, supplying roughly 25-30 mm per week, with open-field adjustments depending on rainfall.

To reduce water loss and suppress weeds, black polyethylene mulch was laid across the soil surface in both environments. It maintained slightly higher soil temperatures early in the season, benefiting eggplant establishment, though this advantage diminishes as summer warms the soil.

Disease and pest control

Disease and pest management was approached through a mix of preventive steps and direct interventions, whenever the situation genuinely required it, following the general principles of Integrated Pest Management (Deguine et al., 2021). Yellow sticky traps were used for monitoring, and treatments relied mainly on potassium soap or neem-based formulations, avoiding synthetic substances in the enclosed space whenever reasonably possible.

To improve pollination, we opened side vents and doors for insect access and introduced bumblebee hives (*Bombus terrestris*) during flowering. Studies show that using bumblebees can increase yields by 20-25% in protected systems (Khalifa et al., 2021).

Data recording and statistical analysis

Data were collected throughout the season, with observations recorded whenever a developmental stage appeared, such as seedlings taking hold after transplanting, the onset of flowering, the first visible fruit set, and later when fruits reached a marketable size. A marked difference in earliness emerged: plants inside the tunnel began flowering roughly 7-10 days ahead of those in the open field. Between the two hybrids, Mirval F1 maintained its reputation for very early maturity, usually reaching the first harvest about 5 days before Black Pearl F1. This tendency was observed in both systems, although the exact calendar dates drifted slightly from one year to the next.

Harvesting was done manually in successive rounds, once fruits showed the usual indicators of commercial maturity, glossy skin and the firmness typical for each hybrid. Harvests continued until yields fell to negligible levels: in early October inside the tunnel, when night temperatures dropped below 10°C, and by mid-September outside, after the first light frosts stopped growth.

For each plot, the total yield in kilograms and converted to a per-hectare basis, was recorded. Fruit counts were also taken to estimate the mean number of fruits per plant. Average fruit weight was determined both from the ratio of total yield to fruit number and from a 20-fruit sample weighed at peak harvest; a procedure that helped smooth out the usual small irregularities in fruit size.

RESULTS AND DISCUSSIONS

The comparison between the two cultivation systems showed marked and consistent differences in total yield per hectare across the three study years. Plants grown in the solar tunnel outperformed those in the open field in every season, and this held true for both hybrids without any real exception. When the averages were considered together, the protected environment produced close to 60% higher yields than the outdoor plots, which more or less aligned with the expectations formed at the outset.

For Mirval F1, the mean yield reached roughly 65.3 t/ha in the tunnel, whereas the same hybrid produced around 45.1 t/ha under open-field conditions. The contrast was sharper for Black Pearl F1, which recorded about 70.4 t/ha under protection but only 40.2 t/ha outside. Expressed in relative terms, Black Pearl gained nearly 75% over its open-field yield, while Mirval showed an increase of about 45%. The ANOVA confirmed the strong effect of the Environment factor ($p < 0.05$), underscoring how a moderated microclimate can, quite literally, reshape production levels (Table 2).

Table 2. Yield performance of eggplant hybrids

Hybrid	Greenhouse yield (t/ha)	Open-field Yield (t/ha)	Yield increase (%)
Mirval F1	65.3	45.1*	45%
Black Pearl F1	70.4*	40.2	75%
Mean (both hybrids)	67.85	42.65	59%

*significance for $p \leq 0.05$

These patterns echo findings reported elsewhere. A study from South Texas observed that organic eggplant grown in high tunnels achieved an 84% yield increase relative to outdoor plants, driven mostly by approximately 63% more fruits per plant and a smaller increase in average fruit weight of about 9% (Shaik et al., 2023). Comparable tendencies were visible in our dataset as well, though the specific components are examined in the next sections.

The yield figures from the trial indicate the advantage of protected cultivation, with both hybrids performing better in the tunnel than in the open field. The extent of the gain did not follow the same pattern across hybrids. The yield comparison of the two hybrids suggests that Black Pearl depends more heavily on a steady microclimate and may cope less well

with the small but persistent stresses that accumulate in open-field settings.

Taken together, the two hybrids produced close to 60% higher yields in the protected environment than in the field plots. This difference appeared each year for both hybrids, despite their distinct growth habits, supporting the idea that controlled structures offer a stable, almost dependable advantage for eggplant cultivation, even if field conditions, as growers know too well, seldom behave exactly the same from one year to another.

Number of fruits and average fruit weight

A closer examination of the yield components revealed distinct differences between the two cultivation systems, as well as between the hybrids themselves. Plants grown inside the greenhouse tended to carry more fruits per plant, and those fruits were, on average, marginally heavier than the ones obtained outdoors. Across years and hybrids, the protected environment produced roughly 30% more fruits per plant, a tendency that stayed surprisingly steady, even if the exact figures varied a little from one season to the next (Table 3).

For Mirval F1, the greenhouse conditions resulted in about 6.8 fruits/plant, compared with roughly 5.0 in the open field. Black Pearl F1 showed the same directional shift but with a sharper contrast: around 5.8 fruits/ plant in the tunnel and only 3.8 outdoors. This wider difference suggests that the shorter and more irregular field season likely restricted Black Pearl from forming a higher fruit load.

Despite these contrasts, Mirval F1 remained the hybrid with the higher fruit number in both environments. Its advantage, about 1.2 fruits/plant in the tunnel and outdoors alike, fits its known morphology of short internodes and a notably strong fruit-setting ability, although in some plots the pattern appeared a bit less tidy than the numbers might imply.

Table 3. Eggplant fruits number from experiment

Hybrid	Greenhouse fruit number	Open-field fruit number	Differences (%)
Mirval F1	6.8*	5*	36%
Black Pearl F1	5.8	3.8	53%
Mean	5.8	3.8	43%

*significance for p ≤0.05

Average fruit weight

The examination of average fruit weight revealed a pattern almost opposite to that observed for fruit number. Black Pearl F1 consistently produced heavier fruits than Mirval F1, both in the tunnel and under field conditions. In the open field, Black Pearl averaged roughly 350 g, whereas Mirval remained closer to 280 g, a difference of about 25%. Under the steadier conditions of the greenhouse, both hybrids increased in weight: Black Pearl reached around 400 g, while Mirval settled near 320 g. The gap between them, usually in the 70-80 g range, stayed surprisingly constant, suggesting a strong genetic control over this trait. Black Pearl is bred as a large-fruited type, typically around 19 × 10 cm with an ovoid or slightly teardrop profile, while Mirval produces more elongated fruits of roughly 20 cm, most often falling in the 250-300 g interval in repeated observations (Table 4).

What emerges quite clearly is that the cultivation environment influenced the fruit number far more than the weight of individual fruits.

Table 4. Eggplant fruit weight from experiment

Hybrid	Greenhouse fruit weight (g)	Open-field fruit weight (g)	Differences (%)
Mirval F1	320	280	14.3%
Black Pearl F1	400*	350*	14.3%
Mean	320	280	14.3%

*significant for p≤0.05

In proportional terms, average fruit weight increased by about 14% in the greenhouse, roughly 40 g for Mirval and about 50 g for Black Pearl. By contrast, fruit number rose by nearly 36% in Mirval and close to 53% in Black Pearl. This pattern indicates that the tunnel enhanced yield chiefly by extending the period during which plants could set fruits and by buffering late-season stress, rather than by making individual fruits substantially heavier.

Debates among growers focus on whether markets prefer smaller or larger fruits, with local demand dictating the preference. Both systems produced sizes within commercial expectations, with the greenhouse increasing both weight and fruit count, which is ideal. The weight differences between hybrids reflect their breeding strategies. Mirval emphasizes early maturity and a heavier fruit load, leading to

smaller fruits. In contrast, Black Pearl produces fewer fruits but allows for greater mass due to a later production peak. This pattern is common: genotypes with high fruit counts yield smaller fruits, while those with moderate counts often produce larger ones. Both can achieve similar total yields but require different management - heavy setters may need fruit thinning, while large-fruited types need careful nutrient management to prevent flower drop.

Earliness and harvest dynamics

Plants grown inside the tunnel-entered production notably sooner, roughly two to three weeks ahead of those in the open field, an advance that carries real weight for growers, since early-season fruit usually commands higher prices.

Mirval F1, owing to its quicker maturity, reached its first marketable stage toward the end of June in the tunnel, at least in 2020 and 2021 when spring came somewhat warmer than expected. Black Pearl F1 followed only shortly after, with initial harvests appearing in the first days of July. In the open field, the calendar shifted backwards: Mirval generally began around 10-15 July, while Black Pearl tended to reach usable maturity closer to the month's end, sometimes even a bit beyond, depending on the weather swings.

These contrasts in maturity rate shaped the seasonal distribution of yield as well. Mirval placed a larger share of its production in the early half of the harvest window, whereas Black Pearl maintained a steadier output and continued fruiting into the later weeks. The divergence was especially clear inside the greenhouse, where Black Pearl still produced reasonably well until late September, while Mirval had already shown a decline, most likely because it had pushed much of its growth and assimilates earlier in the cycle.

In practical terms, Mirval tended to "finish" its main period of productivity sooner, whereas Black Pearl stretched its output across a longer span.

CONCLUSIONS

The comparative assessment of eggplant grown in solar-tunnel structures and in open-field plots, using the hybrids Mirval F1 and Black Pearl F1, brought into view several aspects relevant for sustainable vegetable production. The unheated tunnels created a more buffered microclimate, and the plants, almost predictably, responded with yields roughly 50-70% higher than those obtained outdoors.

The hybrids themselves did not respond identically. Mirval F1, being a very early type, performed reliably even outdoors and maintained a stable number of medium-sized fruits despite the more erratic conditions. Black Pearl F1 expressed its potential far more fully in the extended, calmer tunnel environment, where it produced larger fruits and generally higher yields once the plants had enough time to progress through their cycle. For growers, the results indicate that unheated tunnels represent a practical investment in temperate climates, increasing productivity while softening the impact of weather fluctuations. Even simple structures require attention: ventilation to prevent overheating and ensuring adequate pollination, at times with bumblebees, so fruit set does not suffer. Techniques such as drip irrigation and mulching, applied consistently in this study, ought to be seen as standard components rather than optional additions.

From a wider sustainability perspective, the move toward efficient protected systems advances ecological and economic aims simultaneously. Higher yields per area reduce pressure on land, water is used more sparingly since direct evaporation is minimal, and nutrients remain available instead of being washed away by rain. Although tunnels bring an initial cost, the steadier and higher returns typically balance this investment within a few seasons, strengthening longer-term resilience on the farm.

Stripped of the smaller details, the central point is that choosing the cultivation environment is not merely a technical adjustment but a strategic decision. A basic solar tunnel paired with a hybrid that fits its growth rhythm can lift production considerably without imposing notable ecological burdens. Further economic analysis or work on nutritional traits would refine the picture, although the core finding remains firm: protected cultivation offers a distinct advantage when managed according to the crop's requirements.

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