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Research Article

Comparative Performance Analysis of Monocrystalline and Polycrystalline 50 WP Solar Panels at Varying Solar Radiation Intensities During the Rainy Season

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ABSTRACT

Purpose of the study: This study aims to analyze and compare the performance of monocrystalline and polycrystalline 50 Wp solar panels under varying solar radiation intensity conditions during the rainy season in Surakarta City.

Methodology: A field experimental method was used, installing both panels side by side with identical orientation and tilt angles. Measurements were taken every hour from 07:00 to 17:00 WIB for seven days using an INA219 sensor-based data logger connected to an Arduino Uno microcontroller with SD card storage.

Main Findings: Polycrystalline panels consistently produced higher power output than monocrystalline under low-to-medium irradiance conditions typical of the rainy season, with peak power of 41.323 W versus 39.338 W. Daily peak power fluctuated dramatically from 41.323 W (sunny) to 8.433 W (heavy overcast). Monocrystalline panels showed superior response during morning irradiance transition hours.

Novelty/Originality of this study: This study provides empirical comparative data on both panel types specifically during the Indonesian tropical rainy season in Surakarta, offering practical design recommendations for PLTS systems in high-rainfall tropical regions, including a minimum 75-80% derating factor during rainy season.

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1. INTRODUCTION

The Indonesia as a country located on the equator has a huge potential for solar energy with an average solar radiation intensity of 4.5–4.8 kWh/m²/day throughout the year [1]. This potential makes solar energy one of the most strategic renewable energy sources to be developed in an effort to reduce dependence on fossil fuels that are depleting. The Government of Indonesia through the National Energy General Plan (RUEN) targets the renewable energy mix to reach 23% by 2025, where Solar Power Plants (PLTS) are projected to make a significant contribution to achieving this target.

Solar panels or photovoltaic (PV) are the main technology that utilizes the photovoltaic effect to convert solar radiation energy into electrical energy [1]. Solar panel technology works on the principle of the photoelectric effect, which is the release of electrons from the surface of the semiconductor caused by the collision of photons of sunlight, thus generating a flow of direct electric current (DC). The two types of solar panel technology that are most widely used in Indonesia today are monocrystalline and polycrystalline. Monocrystalline solar panels use a single silicon with high purity so that it is able to produce an energy conversion efficiency ranging from 17–22%, while polycrystalline panels are composed of a combination of smaller silicon crystals with a lower production cost but lower efficiency, about 13–18% [2], [3]. Recent comparative studies further confirm that performance differences between the two panel types are highly sensitive to local climatic conditions and testing methodology, with some studies finding monocrystalline panels superior under certain configurations while others favor polycrystalline under different irradiance and temperature regimes [4], [5].

Solar irradiance intensity is a critical determinant of photovoltaic (PV) module performance, as the amount of sunlight received directly governs the magnitude of voltage, current, and power generated by the panel.The performance of solar panels is greatly influenced by environmental conditions, especially the intensity of solar radiation and the surface temperature of the panels. Previous research results using 50 Wp polycrystalline solar panels showed that the intensity of sunlight was directly proportional to the generated electric current [6]. In sunny weather conditions at 14.00 WIB, the radiation intensity reached 540.18 W/m² with a voltage of 18.425 Volts and a current of 0.81 Ampere. Another study on 100 Wp polycrystalline solar panels proved that the panel surface temperature is inversely proportional to the output power, where polycrystalline solar modules work optimally in the temperature range of 35°C–50°C [7]. Numerous experimental studies conducted in various climatic regions, including hot and arid zones [8], tropical wet and dry seasons [9], and controlled cooling environments [10], [11], have consistently demonstrated that the relative performance advantage between monocrystalline and polycrystalline panels is highly dependent on local irradiance and temperature regimes rather than being universally fixed.

Based on the description above, this study analyzed the comparison of the performance of monocrystalline and polycrystalline solar panels with a capacity of 50 Wp at variations in the intensity of solar radiation during the rainy season in Solo. Furthermore, recent qualitative studies involving solar energy practitioners in Indonesia have highlighted those high humidity and rainfall not only reduce irradiance but also contribute to dust accumulation and corrosion, both of which further degrade long-term panel performance in tropical climates [12].The results of this study are expected to provide scientific contributions in the form of an in-depth understanding of the performance characteristics of the two technologies in Indonesia's tropical climate conditions as well as practical recommendations for the optimal implementation of solar PV systems.

2. RESEARCH METHOD

This This study uses a quantitative experimental method, which is a research approach carried out through testing and direct observation in the field by producing data in the form of measurable, objective, and statistically analyzeable numbers. The experimental approach was chosen because this study involved the manipulation of a free variable in the form of a variation in the intensity of solar radiation against a bound variable in the form of the electrical performance parameters of solar panels.

The test was carried out directly in the field by placing two units of monocrystalline and polycrystalline solar panels with a capacity of 50 Wp each side by side under identical environmental conditions. Installation is carried out in a location free of shading to ensure that both panels receive the same intensity of solar radiation during the testing process.

The measurement system uses the INA219 sensor as a data logger to measure the output voltage and current. Data is stored using an SD card connected to the Arduino Uno microcontroller system. Measurements are carried out every one hour from 07.00 to 17.00 WIB for seven days (4-10 June 2026) with a load in the form of a battery as a measurement indicator. This measurement configuration is consistent with similar data logging architectures reported in recent studies, which confirmed the INA219 sensor's high accuracy for voltage and current monitoring in renewable energy applications [13]-[15]. The INA219 sensor used in this study has a reported voltage measurement accuracy exceeding 99% and current measurement accuracy above 91%, ensuring reliable data acquisition throughout the testing period [16]. Although solar irradiance intensity was not directly measured using a dedicated pyranometer, variations in irradiance levels were inferred from the corresponding fluctuations in voltage, current, and power output recorded across different times of day and weather conditions.

Table 1. Specification of Monocrystalline Solar Panel

Specification Parameters	Remarks
Voltage at Maximum Power (VMP)	18.2 V
Current at Maximum Power (IMP)	2.75 A
Open-Circuit Voltage (VOC)	22.75 V
Short-Circuit Current (ISC)	2.98 A

Table 2. Specification of Polycrystalline Solar Panels

Specification Parameters	Remarks
Voltage at Maximum Power (VMP)	18.2 V
Current at Maximum Power (IMP)	3.34 A
Open-Circuit Voltage (VOC)	21.51 V
Short-Circuit Current (ISC)	3.59 A

The electrical parameters analyzed include the voltage (V), current (A), and power (W) output of each solar panel. The quantitative data is processed and analyzed using descriptive and comparative analysis approaches to produce valid and reliable conclusions.

3. RESULTS AND DISCUSSION

The Data measurement and analysis were obtained from experimental testing of two types of monocrystalline and polycrystalline solar panels with a capacity of 50 Wp carried out during the rainy season in Solo City for seven days. The test was carried out with measurement intervals every one hour from 07.00 to 17.00 WIB, so that representative data was obtained on variations in the intensity of solar radiation in dynamic tropical weather conditions. The power output of each panel was calculated using the basic electrical power formula, namely the product of voltage and current, presented in Equations 1.

Electrical Power = Voltage x Current … (1)

Day 1 Data Collection Results

Table 3. Data Collection Results Day 1

Time	Monocrystalline			Polycrystalline		
	V (volt)	A (ampere)	W (watt)	V (volt)	A (ampere)	W (watt)
07.00	0.501	0.3049	0.153	0.498	0.3108	0.155
08.00	2.519	0.8026	2.022	2.487	0.8305	2.065
09.00	7.928	1.5033	11.918	8.053	1.5633	12.589
10.00	10.075	2.2158	22.324	9.926	2.223	22.065
11.00	12.45	2.6481	32.997	12.569	2.7922	35.095
12.00	13.569	2.8991	39.338	13.731	3.0095	41.323
13.00	13.303	2.7355	36.39	13.471	2.8184	37.967
14.00	13.134	2.2137	29.075	13.13	2.2759	29.883
15.00	12.771	1.4739	18.823	12.944	1.5451	20.000
16.00	11.46	0.797	9.134	11.614	0.827	9.605
17.00	0.501	0.049	0.153	0.498	0.3108	0.155

The measurement data on the first day showed a daily power distribution profile that formed a symmetrical unimodal curve, with the peak power occurring at 12.00 WIB, indicating that the weather conditions during data collection on this day were exceptionally clear with minimal cloud cover, allowing both panels to receive near-optimal solar irradiance throughout the measurement period. Monocrystalline panels recorded a maximum power of 39.338 W at a voltage of 13.569 V and a current of 2.8991 A, while polycrystalline panels reached a peak of 41.323 W at a voltage of 13.731 V and a current of 3.0095 A. This pattern is in line with the movement of the solar zenith angle which reaches the minimum value at noon.

Day 2 Data Collection Results

Table 4. Day 2 Data Collection Results

Time	Monocrystalline			Polycrystalline		
	V (volt)	A (ampere)	W (watt)	V (volt)	A (ampere)	W (watt)
07.00	0.3	0.0883	0.026	0.3	0.0913	0.027
08.00	1.506	0.2424	0.365	1.513	0.2454	0.371
09.00	5.023	0.4568	2.295	5.053	0.4603	2.326
10.00	6.959	0.6681	4.649	7.014	0.6925	4.857
11.00	8.524	0.8035	6.849	8.524	0.8495	7.241
12.00	9.174	0.8748	8.025	9.149	0.913	8.353
13.00	8.881	0.794	7.052	8.731	0.8435	7.365
14.00	7.529	0.65	4.894	7.525	0.6825	5.136

Time	Monocrystalline			Polycrystalline		
	V (volt)	A (ampere)	W (watt)	V (volt)	A (ampere)	W (watt)
15.00	5.471	0.4508	2.466	5.533	0.4559	2.522
16.00	1.995	0.2398	0.478	2.011	0.2451	0.493
17.00	0.3	0.0883	0.026	0.3	0.0913	0.027

On the second day, the polycrystalline panels consistently produced higher output power than monocrystalline in almost the entire measurement time interval. The highest power difference was recorded at 10.00 WIB, which was 0.208 W (monocrystalline: 4.649 W; polycrystalline: 4.857 W). This indicates that under conditions of moderate to low irradiation intensity that are common during the rainy season, polycrystalline panels exhibit slightly better current response, likely due to the more optimal diffuse light absorption characteristics of multi-grain crystal structures [17]. This relatively low power output throughout the day, with a peak of only 8.353 W, indicates that the weather on this day was predominantly overcast with thick cloud cover, significantly limiting the solar irradiance received by both panels.

Day 3 Data Collection Results

Table 5. Data Collection Results Day 3

Time	Monocrystalline			Polycrystalline		
	V (volt)	A (ampere)	W (watt)	V (volt)	A (ampere)	W (watt)
07.00	0.499	0.3053	0.152	0.505	0.3062	0.155
08.00	2.516	0.7841	1.973	2.522	0.8233	2.076
09.00	7.944	1.4826	11.778	7.976	1.5711	12.531
10.00	9.932	2.199	21.84	10.039	2.3079	23.169
11.00	12.501	2.7237	34.049	12.6	2.8222	35.56
12.00	13.711	2.9314	40.192	13.673	2.9786	40.726
13.00	13.43	2.7494	36.924	13.428	2.8186	37.848
14.00	13.087	2.1807	28.539	13.111	2.2704	29.767
15.00	12.767	1.4788	18.88	12.742	1.5431	19.662
16.00	11.584	0.7878	9.126	11.498	0.8156	9.378
17.00	0.499	0.3053	0.152	0.505	0.3062	0.155

The data on the third day showed a very significant increase in power output compared to the second day. The monocrystalline panel recorded a peak power of 40,192 W and a polycrystalline of 40,726 W, both at 12.00 WIB. This spike indicates that the intensity of solar irradiation on the third day is much higher, associated with less cloud cover conditions than the previous day even though it is still in the rainy season period. This indicates that the weather on the third day was sunny with minimal cloud interference, similar to the first day, allowing both panels to operate near their optimal capacity.

Day 4 Data Collection Results

Table 6. Data Collection Results Day 4

Time	Monocrystalline			Polycrystalline		
	V (volt)	A (ampere)	W (watt)	V (volt)	A (ampere)	W (watt)
07.00	0.303	0.0902	0.027	0.3	0.0914	0.027
08.00	1.49	0.2445	0.364	1.509	0.251	0.379
09.00	5.008	0.4578	2.293	5.012	0.4659	2.335
10.00	7.012	0.6611	4.636	7.02	0.6733	4.727
11.00	8.432	0.8261	6.966	8.588	0.8274	7.106
12.00	9.214	0.8847	8.152	9.239	0.9128	8.433
13.00	8.781	0.8112	7.123	8.85	0.849	7.514
14.00	7.505	0.6591	4.947	7.563	0.6705	5.071
15.00	5.541	0.4571	2.533	5.516	0.468	2.581
16.00	2.019	0.2367	0.478	2.018	0.2444	0.493
17.00	0.303	0.0902	0.027	0.3	0.0914	0.027

On the fourth day, the polycrystalline panel again outperformed the monocrystalline at all measurement points. The most prominent power difference occurred at 12.00 WIB of 0.281 W. In percentage terms, the polycrystalline advantage reached around 3.4% at peak conditions. Significant power fluctuations between the first/third day (peak >39 W) and the second/fourth day (peak <8.5 W) confirm that variations in the intensity of solar radiation during the rainy season are unstable and unpredictable (intermittent) [18]. The low peak power recorded on this day, comparable to the second day, suggests that the sky was heavily overcast for most of the measurement period, restricting direct solar exposure to the panels.

Day 5 Data Collection Results

Table 7. Day 5 Data Collection Results

Time	Monocrystalline			Polycrystalline		
	V (volt)	A (ampere)	W (watt)	V (volt)	A (ampere)	W (watt)
07.00	0.544	0.08	0.044	0.565	0.086	0.049
08.00	6.703	0.9873	6.618	2.94	0.4431	1.303
09.00	9.766	1.3107	12.08	5.361	0.8122	4.354
10.00	11.794	1.3107	15.458	10.628	0.1310	13.93
11.00	13.221	1.3107	17.329	13.464	0.1310	17.646
12.00	4.864	0.7162	3.483	5.142	0.7775	3.998
13.00	5.717	0.8479	4.847	6.113	0.9314	5.694
14.00	2.963	0.4348	1.289	3.261	0.4918	1.604
15.00	4.343	0.6325	2.747	5.263	0.7856	4,134
16.00	3.112	2.789	0.478	2.018	0.2444	0.493
17.00	0.403	0.102	0.041	0.3	0.114	0.034

The data of the fifth day showed a very irregular pattern of power distribution. The most striking thing is the extreme current spike at 08.00–11.00 WIB, where the monocrystalline current reaches 13.107 A constantly at three consecutive intervals. This current value indicates the possibility of a cloud lensing effect that temporarily increases the intensity of irradiation beyond standard conditions [19]. This irregular and fluctuating pattern reflects highly variable weather conditions on this day, characterized by intermittent sunny intervals interspersed with sudden cloud cover, typical of unstable rainy-season weather.

Day 6 Data Collection Results

Table 8. Data Collection Results Day 6

Time	Monocrystalline			Polycrystalline		
	V (volt)	A (ampere)	W (watt)	V (volt)	A (ampere)	W (watt)
07.00	0.613	0.0898	0.055	0.617	0.0936	0.058
08.00	6.654	0.981	6.528	2.944	0.4422	1.302
09.00	9.725	1.3107	12.747	5.308	0.8032	4.264
10.00	11.908	1.3107	15.607	10.608	1.3107	13.903
11.00	12.729	1.3107	16.684	13.048	1.3107	17.102
12.00	12.441	1.3107	16.306	12.898	1.3107	16.905
13.00	10.849	1.3107	14.219	11.455	1.3107	15.014
14.00	8.913	1.3107	11.682	10.213	1.3107	13.386
15.00	2.351	0.3456	0.812	2.595	0.3912	1.015
16.00	2.067	0.1358	0.281	1.593	0.2444	0.389
17.00	0.877	0.0578	0.050	0.59	0.1889	0.111

On the sixth day, polycrystalline again excelled at 11.00 WIB with a difference of 0.418 W (17.102 W vs 16.684 W). However, monocrystalline is superior at 08.00 WIB (6,528 W vs 1,302 W). This very striking difference in morning performance is consistent with the pattern of the fifth day, indicating a difference in the response characteristics of the two panel types to the transition of irradiation conditions from low to high. Such inconsistent power readings throughout the day suggest partly cloudy conditions with intermittent sunshine, where brief clear-sky periods were frequently interrupted by passing clouds.

Data Collection Results Day 7

Table 9. Data Collection Results Day 7

Time	Monocrystalline			Polycrystalline		
	V (volt)	A (ampere)	W (watt)	V (volt)	A (ampere)	W (watt)
07.00	0.832	0.1208	0.101	0.78	0.1172	0.091
08.00	6.085	0.8948	5.445	2.859	0.4295	1.228
09.00	9.209	1.3107	12.07	5.28	0.7969	4.207
10.00	11.469	1.3107	15.032	10.38	1.3107	13.605
11.00	12.486	1.3107	16.366	12.854	1.3107	16.848
12.00	12.365	1.3107	16.206	12.815	1.3107	16.796
13.00	8.384	1.2769	10.705	8.851	1.3107	11.601
14.00	8.878	1.3107	11.636	10.16	1.3107	13.316
15.00	5.612	0.8351	4.686	6.484	0.9985	6.474
16.00	2.763	0.348	0.961	3.342	0.359	1.199
17.00	0.889	0.563	0.5	1.009	0.772	0.778

The data of the seventh day again showed the dominant advantage of polycrystalline. The peak power of monocrystalline was recorded at 16,366 W at 11.00 WIB, while polycrystalline reached 16.848 W. At 08.00, monocrystalline again far outperformed polycrystalline with a difference of 4,217 W (5,445 W vs 1,228 W), reinforcing the consistent pattern seen on the fifth and sixth days. This pattern indicates that the seventh day experienced partly cloudy weather with alternating sunny and overcast intervals, consistent with the typical instability of rainy-season weather observed throughout the study period [20]-[22].

Across the seven measurement days, polycrystalline panels recorded a higher output than monocrystalline at nearly every time point, with the daily average difference ranging from 0.002 W to 1.985 W and the largest single gap reaching 41.323 W versus 39.338 W on Day 1. This pattern is physically consistent with how the two cell structures respond to light quality rather than light quantity alone: under diffuse, low-angle irradiance the dominant condition during the rainy season photons scatter across a wider range of incidence angles. The additional grain boundaries in a polycrystalline wafer, which are normally treated as recombination losses under direct, high-intensity sunlight, appear to provide more entry points for scattered light, partially offsetting the technology's lower rated efficiency (13–18% vs. 17–22% for monocrystalline) [23]. In other words, the panel-type advantage observed here is irradiance-*dependent*, not an intrinsic superiority of polycrystalline cells.

This irradiance-dependence is the more decisive variable in the dataset than panel type itself: peak power collapsed from 41.323 W on Day 1 to 8.433 W on Days 2 and 4, a swing far larger than the 0.002–1.985 W gap between panel types on any given day. This matches regional findings that cloud cover fraction is the dominant meteorological driver of PV conversion efficiency in tropical Indonesia, with irradiance reductions of 70–80% under dense cloud [24], and is corroborated by field studies in the same Surakarta region reporting substantially reduced usable sunlight duration and intensity during the rainy season [25], [26], including reported power losses up to 80% from combined cloud cover and dust accumulation [27]. Broader meteorological-correlation studies confirm irradiance as the dominant factor governing PV output across panel technologies generally, not just in this study [28], [29]. Taken together, these findings generalize to a broader principle: in tropical wet-season environments, weather variability outweighs panel technology as a determinant of daily PV yield, and technology choice should be treated as a secondary optimization rather than the primary design driver.

For system design, this implies that off-grid PLTS sizing in high-rainfall tropical regions should prioritize adequate battery storage and backup capacity over marginal gains from panel-technology selection, particularly given current Indonesian regulations that no longer permit grid injection of excess rooftop solar energy [30]-[32]. Where budget is constrained, the data suggest polycrystalline panels can be a reasonable cost-effective choice for rainy-season-dominant sites without a meaningful performance penalty though, as the limitations below indicate, this should be confirmed rather than assumed. Other maintenance factors dust accumulation [33]–[34] and tilt-angle optimization [35], [36] remain relevant levers for long-term yield beyond panel-type selection[37].

Several constraints qualify how far these conclusions can be generalized. First, irradiance was not measured directly with a pyranometer; sunny/overcast conditions were inferred from the panels' own voltage–current output, which is a circular proxy for the variable the study aims to explain [38],[39]. Second, only one unit of each panel type was tested (n = 1), so individual-panel manufacturing variance cannot be separated from technology-level differences. Third, the seven-day window captures only a snapshot of rainy-season variability, not a full seasonal cycle [40]. Fourth, no formal statistical test (e.g., paired t-test) was applied to the daily power differences, several of which (e.g., 0.002–0.281 W) are small relative to plausible sensor noise. Finally, a small number of anomalous readings in the raw dataset including a recorded current of 1.3107 A that recurs identically across multiple non-consecutive hours on Days 5–7 could not be fully reconciled with expected sensor behavior and should be treated as a data-quality caveat rather than a physical finding (the "cloud lensing" explanation offered for Day 5 should accordingly be read as speculative, not confirmed).

Future work should (1) pair panel output with direct pyranometer-based irradiance logging to break the circularity in inferring weather conditions from the panels themselves [41]; (2) test multiple panel units per technology to isolate manufacturing variance from technology effects [42]; (3) extend measurement across a full rainy season (or compare against a matched dry-season dataset) to capture representative seasonal variability; and (4) apply statistical significance testing to daily and hourly power differences before drawing comparative claims. Practically, system designers in similarly humid tropical regions should size storage capacity around worst-case irradiance days (e.g., the 8.433 W minimums observed here) rather than best-case peaks, regardless of which panel technology is selected [43]-[50].

4. CONCLUSION

Based on seven days of measurement and analysis of monocrystalline and polycrystalline 50 Wp solar panels during the rainy season in Surakarta City, this study concludes that panel technology plays a secondary role compared to weather variability in determining photovoltaic performance in this climate. The polycrystalline panel produced a marginally higher output than the monocrystalline panel under the low-to-medium irradiance conditions that dominated the measurement period, with a peak power of 41.323 W compared to 39.338 W and a daily average difference ranging from only 0.002 W to 1.985 W, while the monocrystalline panel showed a superior response during morning irradiance transitions (07:00–08:00 WIB) on the fifth, sixth, and seventh days. This modest and inconsistent gap indicates that the two technologies perform comparably in practice, and that neither can be considered categorically superior for this application. Far more decisive than panel type was the variability in weather itself: peak power swung from 41.323 W under partly sunny conditions to as low as 8.433 W under heavy overcast, a difference an order of magnitude larger than the gap between panel technologies on any given day. This finding, drawn from voltage and current data recorded by the INA219 sensor-based Arduino Uno data logger, indicates that PLTS system design in the Surakarta region should account for a minimum derating factor of 75–80% of installed capacity during the rainy season, with adaptive system sizing and adequate energy storage capacity prioritized ahead of panel-technology selection. Given the marginal performance gap observed, either monocrystalline or polycrystalline panels can be considered a technically acceptable choice for this climate; where a preference is warranted, cost, availability, and installation factors rather than a presumed performance advantage should guide the decision. These conclusions are drawn from a single test site over seven days, with one panel unit of each type and irradiance inferred from panel output rather than measured directly; the derating and design recommendations above should therefore be treated as a starting reference point for system design rather than a precise universal figure, and confirmed against site-specific data where possible. Future work replicating this measurement across multiple panel units, a full rainy season, and direct pyranometer-based irradiance logging would allow these recommendations to be stated with greater confidence.

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AUTHOR CONTRIBUTIONS

Conceptualization, F.F.G.; Methodology, F.F.G.; Software, F.F.G.; Validation, F.F.G.; Formal Analysis, F.F.G.; Investigation, F.F.G.; Resources, F.F.G.; Data Curation, F.F.G.; Writing – Original Draft Preparation, F.F.G.; Writing – Review & Editing, F.F.G.; Visualization, F.F.G.; Supervision, Muhammad Kusban.

CONFLICTS OF INTEREST

The author(s) declare no conflict of interest.

INFORMED CONSENT STATEMENT

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USE OF ARTIFICIAL INTELLIGENCE (AI)-ASSISTED TECHNOLOGY

The authors declare that no artificial intelligence (AI) tools were used in the generation, analysis, or writing of this manuscript. All aspects of the research, including data collection, interpretation, and manuscript preparation, were carried out entirely by the authors without the assistance of AI-based technologies.

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