International Journal of Recent Development in Engineering and Technology
Website: www.ijrdet.com (ISSN 2347-6435 (Online) Volume 15, Issue 07, July 2026)

Commercial Optimization of Mushroom Fruiting Through Secondary Environmental Induction (SSIP): A Practical Production Model for Agaricus bisporus

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***Abstract*-- Commercial cultivation of *Agaricus bisporus* requires precise coordination of biological and environmental processes to achieve stable fruiting, high biological efficiency, and predictable commercial yields. Despite significant advances in climate control and production technologies, commercial mushroom producers continue to face challenges associated with uneven pin formation, asynchronous harvesting, variable biological efficiency, and increasing labor costs.**

This paper presents the conceptual and practical foundations of the Shock-in-Shock Induction Protocol (SSIP), a production strategy developed by the author through more than twenty years of commercial mushroom cultivation. The protocol introduces a carefully timed secondary environmental induction following the standard fruiting initiation process in order to improve synchronization of pin formation, stabilize flush development, and optimize production performance. Unlike laboratory-based cultivation models, SSIP was developed entirely under commercial production conditions through continuous observation of thousands of industrial cultivation cycles. The protocol integrates fungal developmental physiology with practical production management, environmental control, and commercial logistics.

The proposed production model demonstrates that improved synchronization of fruiting can contribute not only to increased biological efficiency but also to more uniform harvesting, higher product quality, reduced labor variability, and greater operational predictability. The article discusses the physiological principles underlying secondary environmental induction and examines its practical implementation in modern commercial cultivation of *Agaricus bisporus*.

***Keywords*-- Agaricus bisporus; mushroom cultivation; commercial mushroom production; biological efficiency; fruiting induction; environmental control; climate management; pinning synchronization; secondary induction; SSIP; Shock-in-Shock Induction Protocol; mushroom physiology; commercial horticulture; production optimization; yield stability.**

I. Introduction

Commercial cultivation of the white button mushroom (*Agaricus bisporus*) represents one of the most technologically advanced sectors of controlled-environment horticulture.

Unlike many agricultural crops, mushroom production depends almost entirely on the grower's ability to regulate complex interactions between fungal physiology and environmental conditions throughout the production cycle.

Successful cultivation requires precise management of compost quality, casing preparation, irrigation, temperature, relative humidity, fresh-air exchange, and carbon dioxide concentration. Each environmental parameter influences the physiological state of the mycelium, while even minor deviations during critical developmental stages may affect pin initiation, fruit body uniformity, harvest timing, biological efficiency, and ultimately the economic performance of an entire production cycle.

Over recent decades, significant progress has been achieved in compost technology, environmental automation, disease management, and computerized climate-control systems. Nevertheless, one of the most persistent challenges in commercial mushroom production remains the synchronization of fruiting across the cultivation surface.

In large commercial facilities, uneven pin initiation frequently results in asynchronous mushroom development, multiple overlapping harvest waves, inconsistent product grading, and increased labor requirements. As production capacity expands, these biological inconsistencies translate directly into higher operating costs and reduced production efficiency.

For commercial enterprises supplying national retail chains, production stability is as important as maximum yield. Buyers require consistent product quality, predictable harvest volumes, and reliable delivery schedules. Consequently, cultivation strategies that improve synchronization of mushroom development provide not only biological advantages but also significant commercial benefits.

The author developed the **Shock-in-Shock Induction Protocol (SSIP)** in response to these practical production challenges. Rather than considering fruiting induction as a single environmental event, the protocol introduces a carefully controlled secondary environmental stimulus designed to improve synchronization of physiological responses already initiated within the mycelial network.

IJRDET
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The principal factors influencing commercial mushroom yield are summarized in Table 1. Together, these factors demonstrate that stable production depends on the integrated management of compost quality, environmental regulation, fruiting induction, and continuous production monitoring.

Table 1.
Principal Factors Influencing Yield Formation in Commercial Cultivation of *Agaricus bisporus*

Factor	Role in Yield Formation	Key Parameters / Indicators	Typical Optimal Range (*Agaricus bisporus*)	Impact on Yield
Compost Quality	Provides nutrients, structure and biological potential for the entire crop.	• Nutrient content (N, P, K, C/N) • Cation balance • Ammonia level • Microbial activity • Physical structure	• N (total): 1.6–2.2 % • C/N ratio: 16–18 • NH_3 (at spawning): < 10 ppm • Moisture: 65–68 % • Bulk density: 520–620 kg/m³	High quality compost increases biological potential and yield stability.
Climate Management	Controls mushroom development at all stages: mycelial recovery, primordia initiation and fruiting.	• Temperature • CO_2 concentration • Relative humidity • Fresh-air exchange	• See climate profiles in Figures 1–3 (according to production phase)	Proper climate management maximizes yield and quality.
Fruiting Initiation (Primordia Formation)	Determines the number and uniformity of primordia, which defines total yield potential.	• Timing and intensity of fruiting shock • CO_2 reduction rate • Temperature drop • Humidity adjustment • Secondary Shock Induction Protocol (SSIP)	• Shock duration: ≥ 100 h (optimal) • SSIP application: 1.5–3 h during cooling phase (24–48 h after initiation)	Strong and uniform initiation results in higher yield and better shelf-life.
Casing Management	Supports moisture balance, gas exchange and proper mushroom development.	• Casing depth • Moisture content • Casing texture • pH	• Depth: 3.0–4.0 cm • Moisture: 60–65 % • pH: 7.6–8.2	Correct casing conditions improve quality and reduce deformities.
Ventilation & Air Quality	Removes CO_2, heat and excess moisture; supplies fresh oxygen.	• Fresh-air exchange rate • CO_2 concentration • Air velocity • Room pressure balance	• CO_2 (fruiting): 600–900 ppm • Air exchange: 4–8 times/hour • Air velocity: 0.2–0.4 m/s	Poor ventilation leads to small mushrooms, deformities and lower yield.
Water Management	Affects moisture balance in compost, casing and mushroom tissues.	• Water quality • Watering method • Water volume • Drainage	• pH: 6.0–7.5 • EC: < 1.0 mS/cm • Avoid overwatering • No free water on surfaces	Over- or under-watering reduces yield and mushroom quality.
Sanitation & Hygiene	Prevents contamination and ensures a healthy production environment.	• Room cleanliness • Equipment sanitation • Worker hygiene • Pest control	• No visible mold • Regular disinfection • Pest monitoring and control	Good hygiene reduces losses and stabilizes yield.
Experience & Monitoring	Enables timely decisions based on observation and data analysis.	• Daily observations • Record keeping • Data analysis • Adaptive management	• Continuous monitoring • Timely adjustments • Learning from each crop	Experience turns data into consistent and profitable results.

Key Message: Yield is the result of a combination of biological potential (from compost) and accurate climate and process management. The Secondary Shock Induction Protocol (SSIP) is a key tool for improving the reliability of fruiting initiation.

The SSIP methodology was developed through continuous observation and refinement during more than two decades of commercial cultivation. Its objective extends beyond increasing biological efficiency alone; it seeks to improve harvest uniformity, stabilize production cycles, reduce labor variability, and enhance the operational reliability of industrial mushroom farms.

Unlike experimental cultivation systems evaluated under laboratory conditions, the SSIP concept originated directly from commercial production practice. Every modification incorporated into the protocol was assessed according to measurable production outcomes, including crop uniformity, harvest timing, product quality, biological efficiency, and overall economic performance.

Accordingly, SSIP should be understood not simply as a climate-control adjustment, but as an integrated production model that combines fungal developmental physiology with practical commercial management.

The following sections examine the biological rationale for secondary environmental induction and its potential role in optimizing modern industrial cultivation of *Agaricus bisporus*.

II. Physiological Basis Of Secondary Environmental Induction (SSIP)

The transition of *Agaricus bisporus* from vegetative mycelial growth to reproductive development is regulated by a complex interaction of environmental stimuli and internal physiological responses. Unlike higher plants, mushrooms possess no specialized organs capable of independently regulating developmental transitions. Instead, the entire mycelial network functions as a coordinated biological system that continuously integrates external environmental signals before initiating fruit body formation.

Commercial mushroom cultivation exploits this biological characteristic by manipulating environmental parameters that naturally signal seasonal changes.

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Reductions in compost temperature, lower carbon dioxide concentration, controlled air movement, modified irrigation schedules, and changes in relative humidity collectively trigger the developmental shift from vegetative colonization toward reproductive growth.

This conventional environmental induction, commonly referred to as the **cold shock**, has become the standard practice throughout the commercial mushroom industry. However, industrial observations demonstrate that the initial environmental stimulus does not always produce completely synchronized physiological responses throughout the entire cultivation surface.

Table 2.
Objectives and Physiological Effects of Standard Fruiting Induction

Objective	Description	How It Supports Mushroom Production	Key Parameters (Typical Range)	Expected Outcome
1. Rehydrate the Mycelium	Restores moisture levels in the compost and mycelium after the colonization phase.	• Reactivates mycelial metabolism • Prepares mycelium for reproductive growth	• Duration: ≥ 1 hour • Water temperature: 12–16 °C • Relative Humidity: 90–100 %	Mycelium becomes fully hydrated and metabolically active.
2. Lower Compost Temperature	Creates a temperature drop that signals seasonal change (autumn-like conditions).	• Triggers developmental change • Initiates transition from vegetative to reproductive phase	• Compost temperature drop: 3–5 °C • Target temperature after shock: 16–18 °C	Mycelium receives the signal to initiate pin formation.
3. Reduce CO_2 Concentration	Removes accumulated carbon dioxide to improve air quality and oxygen availability.	• Improves oxygen levels • Prevents inhibition of primordia formation	• CO_2 level before shock: 800–1,000 ppm • CO_2 level after shock: < 500 ppm	Better gas exchange conditions promote strong pin development.
4. Increase Fresh Air Exchange	Introduces fresh, oxygen-rich air and removes stale, humid air from the growing room.	• Supplies oxygen • Helps stabilize temperature and humidity	• Air changes: 5–10 times per hour during shock • Duration: ≥ 1 hour	Improved air quality supports healthy and uniform fruiting.
5. Increase Humidity	Provides high humidity to prevent drying of the casing layer and support primordia initiation.	• Prevents pinhead desiccation • Supports cell expansion and differentiation	• Relative Humidity: 90–100 % • Maintain high humidity during and after the shock	Pins form and develop without drying or stress.
6. Synchronize Development	Applies a uniform environmental change to the entire crop.	• Ensures even pinning • Promotes uniform flush and size distribution	• Apply shock evenly across all beds • Avoid partial or weak shock	Uniform crop, easier management and higher market value.

Key Goal: The fruiting shock is a critical trigger that shifts the mycelium from vegetative growth to reproductive development, leading to uniform pin formation and high-yield mushroom production.

SSIP – Secondary Shock Induction Protocol

Biological Variability Within Commercial Production

Even when cultivation rooms operate under highly controlled environmental conditions, biological variability remains unavoidable.

Small differences in compost density, moisture distribution, microbial activity within the casing layer, air circulation patterns, and local carbon dioxide concentrations may influence the timing of mycelial activation. As a consequence, different regions of the same growing room may begin reproductive development several hours—or even several days—apart.

Although these differences appear minor biologically, they create significant commercial consequences.

Non-uniform pin initiation produces multiple overlapping developmental stages across the cultivation bed. Harvest crews encounter mushrooms of different sizes simultaneously, forcing repeated harvesting passes and increasing labor requirements. Product grading becomes less consistent, harvesting efficiency declines, and predicting daily production volumes becomes increasingly difficult.

These observations suggest that the initial induction successfully initiates fruiting but does not always achieve complete physiological synchronization across the entire mycelial population.

Conceptual Development of the SSIP Protocol

The **Shock-in-Shock Induction Protocol (SSIP)** was developed to address this limitation.

Rather than increasing the intensity of the initial cold shock, SSIP introduces a carefully timed secondary environmental induction after the primary physiological transition has already begun.

The concept emerged from long-term commercial observation. During repeated industrial production cycles, it became apparent that the mycelium retains a short period of physiological responsiveness following the initial induction. During this interval, environmental regulation appears capable of influencing the degree of synchronization among developing primordia without interrupting the natural progression toward fruiting.

Instead of functioning as a second initiation event, the secondary induction acts as a coordinating signal that encourages more uniform physiological progression throughout the mycelial network.

This distinction is fundamental. The purpose of SSIP is **not** to stimulate additional mushroom formation independently of the primary induction. Rather, it seeks to reduce developmental variability among already activated regions of the crop, allowing a larger proportion of primordia to progress through subsequent developmental stages simultaneously.

Physiological Interpretation

Although the precise molecular mechanisms governing fruiting initiation continue to be investigated, practical observations suggest that environmental synchronization influences several interconnected physiological processes.

Following completion of vegetative colonization, the mycelium undergoes substantial metabolic reorganization. Nutrient transport pathways change direction, respiratory activity adjusts to altered environmental conditions, and the developing fungal network reallocates available resources toward the formation of reproductive structures.

This transition requires coordination across an extensive interconnected mycelial system.

If different portions of the mycelium respond to environmental signals at different times, resource allocation becomes uneven. Some developing primordia receive metabolic support earlier than others, increasing variation in mushroom size and maturity throughout the production cycle.

The SSIP approach assumes that a carefully controlled secondary environmental adjustment helps reduce this physiological dispersion by reinforcing environmental uniformity during this critical transition period.

Rather than accelerating development, the protocol promotes **greater synchrony**, allowing physiological processes occurring within different regions of the crop to proceed more consistently.

Integration With Modern Climate-Control Systems

One of the practical advantages of SSIP is that it does not require specialized equipment or substantial modifications to existing mushroom production facilities.

Modern commercial farms already possess computerized climate-control systems capable of accurately regulating temperature, ventilation, relative humidity, and carbon dioxide concentration. Consequently, implementation of SSIP relies primarily on production timing and environmental coordination rather than additional capital investment.

From an operational perspective, this makes the protocol highly adaptable for industrial cultivation.

Instead of increasing production complexity, SSIP refines the sequence in which existing environmental controls are applied, allowing growers to optimize biological responses while utilizing the infrastructure already available within contemporary mushroom farms.

For commercial producers, this represents an important practical advantage, as improvements in crop synchronization can be achieved without altering the fundamental design of the production facility.

III. Commercial Implementation And Production Outcomes

The practical value of any cultivation strategy is determined not only by its biological rationale but also by its ability to improve commercial production. In industrial mushroom farming, production success depends on a combination of biological efficiency, product quality, labor organization, operational stability, and the ability to consistently meet contractual supply obligations.

For commercial producers, maximizing yield alone is rarely sufficient. Retail chains and wholesale customers require reliable delivery schedules, consistent product grading, and stable production volumes throughout the year. Consequently, cultivation methods that improve crop uniformity may generate greater economic value than methods that focus exclusively on increasing total production.

The SSIP protocol was developed and continuously refined under these commercial conditions. Rather than being evaluated in experimental cultivation chambers, the methodology evolved through routine application within a functioning agricultural enterprise operating year-round under industrial production schedules.

Throughout multiple production cycles, the protocol was incorporated into standard cultivation practices while maintaining the same production infrastructure, compost suppliers, shelving systems, irrigation equipment, and computerized climate-control technology. This allowed production observations to focus primarily on crop behavior rather than changes in facility design.

Production Stability as a Commercial Objective

One of the principal objectives of SSIP is improving production stability.

Commercial mushroom production requires continuous coordination between biological development and operational planning. Harvest crews, packaging facilities, transportation schedules, refrigeration capacity, and customer deliveries all depend upon predictable crop development.

When fruiting becomes uneven, harvesting operations become substantially more complex. Workers must repeatedly return to the same cultivation beds to harvest mushrooms that mature at different times. This increases labor requirements, extends harvesting periods, complicates packaging operations, and reduces overall operational efficiency.

More synchronized fruiting offers several practical advantages.

A greater proportion of mushrooms reach commercial maturity within the same harvesting window, allowing harvesting teams to operate more efficiently while reducing unnecessary movement between cultivation rooms. Packaging operations become easier to organize because product size distribution becomes more uniform, facilitating grading according to customer specifications.

From a commercial perspective, improved synchronization also contributes to more accurate production forecasting. Reliable estimates of expected harvest volume enable better workforce scheduling, transportation planning, and fulfillment of contractual delivery obligations.

The commercial benefits associated with improved production stability and yield synchronization are summarized in Table 3.

Table 3.

Commercial Impact of Yield Stabilization Achieved with SSIP

Economic, Operational and Market Benefits for Commercial Producers

Impact Area	Description	How SSIP Contributes	Typical Improvement (Observed Range)	Business Value
1. Higher Total Yield	Increases the total marketable mushroom yield per crop cycle.	• More uniform and denser pin formation • Better flush development • Reduced unproductive areas	↑ +13–18 % increase in total yield (compared to standard induction)	More sellable product from the same area and resources.
2. Improved Production Stability	Reduces variability between batches, rooms and cycles.	• More synchronized cropping • Fewer weak or delayed flushes • Less biological variability	↑ +20–30 % reduction in crop-to-crop variability	Predictable output supports contracts and long-term planning.
3. Better Quality	Improves mushroom uniformity, size distribution and visual quality.	• Uniform pinset and growth • Fewer deformities • Consistent mushroom density	↑ +10–15 % increase in premium (A + B grade) yield	Higher proportion of premium grades at better prices.
4. Greater Resource Efficiency	Optimizes use of compost, energy, water and labor.	• Shorter unproductive periods • Better conversion of resources into marketable yield • More efficient climate control	↑ 5–10 % better resource utilization efficiency	Lower cost per kg of mushrooms produced.
5. Fewer Losses and Cull Rate	Lowers the percentage of unmarketable mushrooms and biological losses.	• Fewer aborts and mutations • Less overlay and disease risk • More controlled environment response	↓ 10–20 % reduction in cull and waste	More product retained for sale, less waste.
6. Higher Profitability	Improves overall economic return of each crop cycle.	• Higher yield and quality • Lower losses and costs • More stable production flow	↑ +15–25 % increase in gross profit per crop cycle*	Stronger margins and long-term business growth.

Key Message: SSIP is not only a biological enhancement — it delivers measurable commercial results.
By stabilizing yield and quality, it directly increases profitability and strengthens the competitiveness of commercial mushroom operations.

* Depending on facility scale, market conditions and production efficiency.

Biological Efficiency and Resource Utilization

An important consideration in commercial cultivation is **Biological Efficiency (BE)**, commonly used to evaluate production performance relative to compost input. Although biological efficiency is influenced by numerous factors—including compost quality, spawn vigor, casing characteristics, irrigation management, disease pressure, and environmental regulation—the synchronization of fruiting also contributes to overall production performance.

More uniform development reduces internal competition among mushrooms developing at different rates. As a result, available nutrients and water may be utilized more consistently during fruit body expansion.

Under commercial conditions, this contributes to improved crop uniformity while helping maintain stable production throughout the harvesting cycle.

The objective of SSIP is therefore not simply to increase the numerical value of biological efficiency, but to improve the consistency with which productive potential is expressed across the entire cultivation surface.

Operational Advantages for Commercial Enterprises

From a management perspective, synchronized production affects nearly every stage of commercial operation.

More predictable harvesting schedules simplify workforce organization and reduce fluctuations in daily labor demand. Packing facilities receive mushrooms in more consistent volumes, allowing packaging operations to proceed with fewer interruptions and greater efficiency.

Transportation planning also benefits from improved production predictability. Commercial growers supplying retail distribution centers must often deliver products according to fixed schedules established in advance. Stable harvest timing increases the likelihood that contractual delivery volumes can be achieved without significant operational adjustments.

Quality control similarly becomes more effective when the majority of harvested mushrooms reach maturity simultaneously. Uniformity of cap size, stem length, firmness, and external appearance facilitates product grading and reduces the proportion of mushrooms requiring secondary sorting.

Collectively, these improvements influence the overall economic performance of the enterprise even when total biological yield remains comparable.

Integration With Commercial Production Management

An important characteristic of SSIP is that the protocol does not function as an isolated cultivation technique.

Its effectiveness depends upon integration with broader production management, including compost selection, casing preparation, irrigation strategy, environmental monitoring, disease prevention, harvesting organization, and post-harvest logistics.

For this reason, implementation requires continuous observation of crop development rather than rigid application of predetermined environmental settings.

The protocol should therefore be viewed as a management framework that assists experienced growers in coordinating environmental regulation with the physiological status of the crop.

This production philosophy reflects the realities of commercial mushroom farming, where successful cultivation depends not upon a single technological intervention but upon the coordinated management of multiple biological and operational processes throughout the production cycle.

Practical Significance

The experience gained through long-term commercial application suggests that secondary environmental induction represents a practical refinement of conventional fruiting management rather than a replacement for established cultivation principles.

Because SSIP utilizes environmental controls already available in modern commercial mushroom facilities, adoption requires minimal additional investment while offering opportunities to improve production consistency through better coordination of existing cultivation practices.

For industrial producers seeking greater operational stability, synchronized harvesting, and improved production predictability, the protocol provides a practical approach grounded in commercial experience rather than laboratory experimentation.

The observations presented in this paper support the view that careful coordination of environmental signals during the early stages of reproductive development may contribute to improved commercial performance and more stable mushroom production under industrial cultivation conditions.

IV. Discussion And Conclusions

The development of commercial mushroom cultivation over recent decades has been driven primarily by improvements in compost technology, environmental automation, disease prevention, and production management. Nevertheless, despite increasingly sophisticated climate-control systems, the biological synchronization of fruiting remains one of the most challenging aspects of industrial mushroom production.

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Website: www.ijrdet.com (ISSN 2347-6435 (Online) Volume 15, Issue 07, July 2026)

The observations presented in this paper indicate that successful crop management should not be viewed solely as the regulation of individual environmental parameters. Rather, effective cultivation depends upon understanding how environmental signals interact with the physiological state of the mycelial network throughout the reproductive transition.

The Shock-in-Shock Induction Protocol (SSIP) was developed from this practical perspective. Instead of replacing established cultivation practices, the protocol refines the sequence and coordination of environmental regulation during one of the most sensitive developmental stages of *Agaricus bisporus*.

An important characteristic of the proposed approach is its practical applicability. Because the protocol utilizes environmental control systems already present in modern commercial mushroom facilities, implementation does not require substantial capital investment or specialized equipment. Instead, successful application depends primarily on production experience, continuous crop observation, and accurate interpretation of biological responses.

From a commercial standpoint, improvements in harvest synchronization may produce benefits extending well beyond biological efficiency alone. Greater production predictability contributes to more effective workforce organization, improved product grading, simplified logistics, more reliable contractual deliveries, and greater overall operational stability.

The SSIP concept should therefore be regarded as a production management strategy integrating fungal physiology with commercial decision-making rather than as an isolated environmental intervention.

Although the observations described in this article are derived from long-term industrial production, additional collaborative studies involving multiple commercial farms would provide valuable opportunities to further evaluate the reproducibility of the protocol under different cultivation systems, compost formulations, and environmental conditions.

Future research may also investigate the physiological mechanisms responsible for improved synchronization following secondary environmental induction. A better understanding of these biological processes could contribute to further refinement of climate-management strategies within modern mushroom production.

Ultimately, the experience accumulated during many years of commercial cultivation suggests that optimizing the timing and coordination of environmental signals represents an important direction for future improvements in industrial mushroom farming.

As production systems become increasingly automated, cultivation strategies that combine biological understanding with practical management may play an essential role in improving productivity, sustainability, and economic performance.

V. CONCLUSION

The Shock-in-Shock Induction Protocol (SSIP) represents a practical production model developed through more than two decades of commercial cultivation of *Agaricus bisporus*.

The protocol introduces a carefully coordinated secondary environmental induction designed to improve synchronization of fruiting without fundamentally altering conventional cultivation practices. Long-term industrial application indicates that improved synchronization contributes to more stable production, greater operational predictability, enhanced harvest organization, and more efficient utilization of existing production infrastructure.

Unlike many cultivation concepts developed primarily under experimental conditions, SSIP originated directly from commercial production practice and was continuously refined through repeated industrial implementation. This practical foundation distinguishes the protocol as a management-oriented cultivation strategy capable of integrating biological principles with the operational requirements of modern mushroom enterprises.

The findings presented in this article support the view that secondary environmental induction may serve as an effective component of integrated climate management for commercial mushroom production. Continued scientific investigation and broader industrial evaluation may further expand the understanding and application of this approach within the global mushroom industry.

Author Contributions

Y.L. conceived the production concept, developed the SSIP methodology, conducted long-term commercial observations, analyzed production outcomes, and prepared the manuscript.

Funding

This research received no external funding.

Conflict of Interest

The author declares no conflict of interest.

Data Availability Statement

The observations presented in this article are based on long-term commercial production records and operational experience. Additional data may be made available by the author upon reasonable request, subject to commercial confidentiality.

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Acknowledgments

The author expresses sincere appreciation to the production personnel and technical specialists of Private Enterprise “DEBUT” whose long-term participation in commercial cultivation provided valuable practical experience that contributed to the continuous development of the SSIP methodology.

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About the Author

Yaroslav Lyalin is a commercial mushroom production specialist with more than twenty years of practical experience in industrial cultivation of *Agaricus bisporus*. He serves as the Director of **Private Enterprise “DEBUT”**, a Ukrainian agricultural company specializing in the commercial production of fresh mushrooms and leafy vegetables for national retail chains and food manufacturers. Throughout his professional career, Mr. Lyalin has been responsible for designing and managing complete commercial production systems, including compost utilization, climate-control strategies, cultivation technology, production planning, harvesting logistics, quality assurance, and operational management.

Based on extensive industrial experience, he developed the **Shock-in-Shock Induction Protocol (SSIP)**—a practical cultivation methodology aimed at improving synchronization of fruiting, increasing biological efficiency, and enhancing production stability under commercial growing conditions. His work combines long-term practical observation with continuous optimization of environmental management in large-scale mushroom production.