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Research Article

Utilization of an Intelligent Electrohydrodynamic Dryer to Improve Drying Efficiency of Camellia Seeds

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Abstract

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This study investigated the application of electrohydrodynamic (EHD) drying technology, utilizing a self-developed intelligent EHD dryer for drying the seeds of *Camellia brevistyla*, a native species of Taiwan, to compare its performance with the traditional sun drying method. The effects of the EHD dryer on drying efficiency of the seeds, and the resulting cold-pressed oil quality, including acid value (AV) and peroxide value (POV), and oil oxidative stability index (OSI) as well, were evaluated. Two batches of camellia seeds were conducted, and the EHD drying was executed at 42℃ to reach the average high temperature during the sun-drying period. Results showed that the intelligent EHD method significantly enhanced drying efficiency, resulting in a shorter drying time (48 h) compared to the sun drying method (9 d). The intelligent EHD dryer exhibited uniform drying and minimized the need for manual seed turning. Oil quality analyses revealed that the intelligent EHD drying exhibited significantly lower AV and POV values compared to the oil obtained via traditional sun drying, indicating superior oil quality. The OSI and sensory evaluation of flavor characteristics were similar for both methods. In summary, applying the intelligent EHD dryer to dry camellia seeds improves drying efficiency and enhances the quality of the pressed oil, thereby demonstrating high potential for further utilization.

Key words: *Camellia brevistyla*, Camellia seeds, Seeds drying method, Electrohydrodynamic drying, Oil quality.

INTRODUCTION

The oil-seed camellia tree (*Camellia oleifera* and *C. brevistyla*), a member of the Theaceae family, is an evergreen shrub or small tree cultivated in Taiwan for its high oil-yielding seeds, commonly referred to as camellia seeds. These seeds contain 30–50% oil, which is extracted to produce what is known locally as "bitter tea oil," and internationally as camellia oil or Tsubaki oil. For consistency, the term "camellia oil" is used throughout this paper. In Taiwan, *C. oleifera* is primarily grown in central, southern, and eastern mountain regions due to its tolerance of higher temperatures, while *C. brevistyla* is better adapted to cooler climates and is mainly cultivated in northern mountainous areas such as Miaoli. These species exhibit distinct physiological traits- for example, *C. brevistyla* is commonly used as a rootstock for

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grafting *C. oleifera*, whereas the reverse combination has limited success.

It is vital to distinguish camellia oil from tea seed oil derived from *C. sinensis*, the tea plant primarily cultivated for beverages. Tea seed oil has a lower oil content (~ 20%) and a fatty acid composition closer to that of sesame or peanut oil (Hsieh *et al*. 2013). In contrast, camellia oil resembles olive oil in its high oleic acid content (70–80%) (Haiyan *et al*. 2007), which is associated with cardiovascular health benefits (Kris-Etherton 1999; Sales-Campos *et al*. 2013). In addition, the polyphenolic compounds in camellia oil contribute antioxidant activity and enhance oxidative stability (Cicerale *et al*. 2010; Ajal *et al*. 2021), making it a nutritionally and functionally valuable oil.

Due to Taiwan's hot and humid climate, freshly harvested camellia seeds are highly susceptible to infestation by pests, mold, and bacteria, all of which can degrade seed quality and negatively impact the resulting oil. Drying is therefore an essential postharvest step to reduce seed moisture, inhibit microbial activity, and ensure oil stability during storage. Sun drying is the most commonly used method due to its simplicity and zero energy cost. However, it has several well-documented drawbacks, including lengthy drying times, high labor demands, poor process control, and large spatial requirements. Additionally, exposure to dust, insects, and other contaminants during open-air drying can compromise oil quality (Kooli *et al*. 2007; Zhang *et al*. 2016). A more efficient, hygienic, and controlled drying method is thus necessary to improve oil retention and maintain the quality of camellia seeds. Beyond preservation, an optimized drying process also contributes to improved appearance, reduced shrinkage, higher rehydration capacity, and better packaging and transport efficiency (Kamarulzaman *et al*. 2021).

To address the limitations of traditional drying methods, electrical and electrochemical technologies have been increasingly explored in the food processing industry. Among them, pulsed electric fields (PEF), moderate electric fields (MEF), and high-voltage electric fields (HVEF) have shown potential in applications such as microbial inactivation, enzyme modulation, and structural modification of food matrices. In particular, HVEF has been applied to drying processes, where static electric fields or high-voltage discharges accelerate moisture migration and reduce microbial activity at relatively low temperatures. These non-thermal drying approaches have been shown to improve drying efficiency and product quality while minimizing thermal damage, as demonstrated in the postharvest treatment of mushrooms and other fresh produce (Lin *et al*. 2020). In that study, high-voltage electric field (HVEF) treatment was applied during storage of *Pleurotus eryngii*, effectively delaying browning, reducing microbial growth, and extending shelf life from 9 to 21 d. The application of an electric field not only maintained the firmness and color of mushrooms but also significantly reduced storage losses, highlighting the practical benefits of non-thermal electrical preservation technologies in highly perishable agricultural products.

Electrohydrodynamic (EHD) drying, derived from the principles of high-voltage electrical discharge, represents a more recent and innovative advancement in non-thermal drying technology. Unlike conventional HVEF systems, EHD drying utilizes corona discharge to generate ion wind- a stream of charged particles that enhances surface moisture removal under ambient conditions. While this mechanism has been studied in experimental contexts, its application in practical-scale drying systems remains limited. The present study, therefore, contributes original work by integrating an intelligent EHD drying system into agricultural drying applications, specifically for camellia seeds. As illustrated in Fig. 1A, the EHD drying mechanism is based on corona discharge between a high-voltage emitter and a grounded collector, which creates a unidirectional ion wind that facilitates convective mass transfer. In this study, a wire-type emitter electrode was adopted (Fig. 1B), allowing for stable discharge and uniform airflow across the

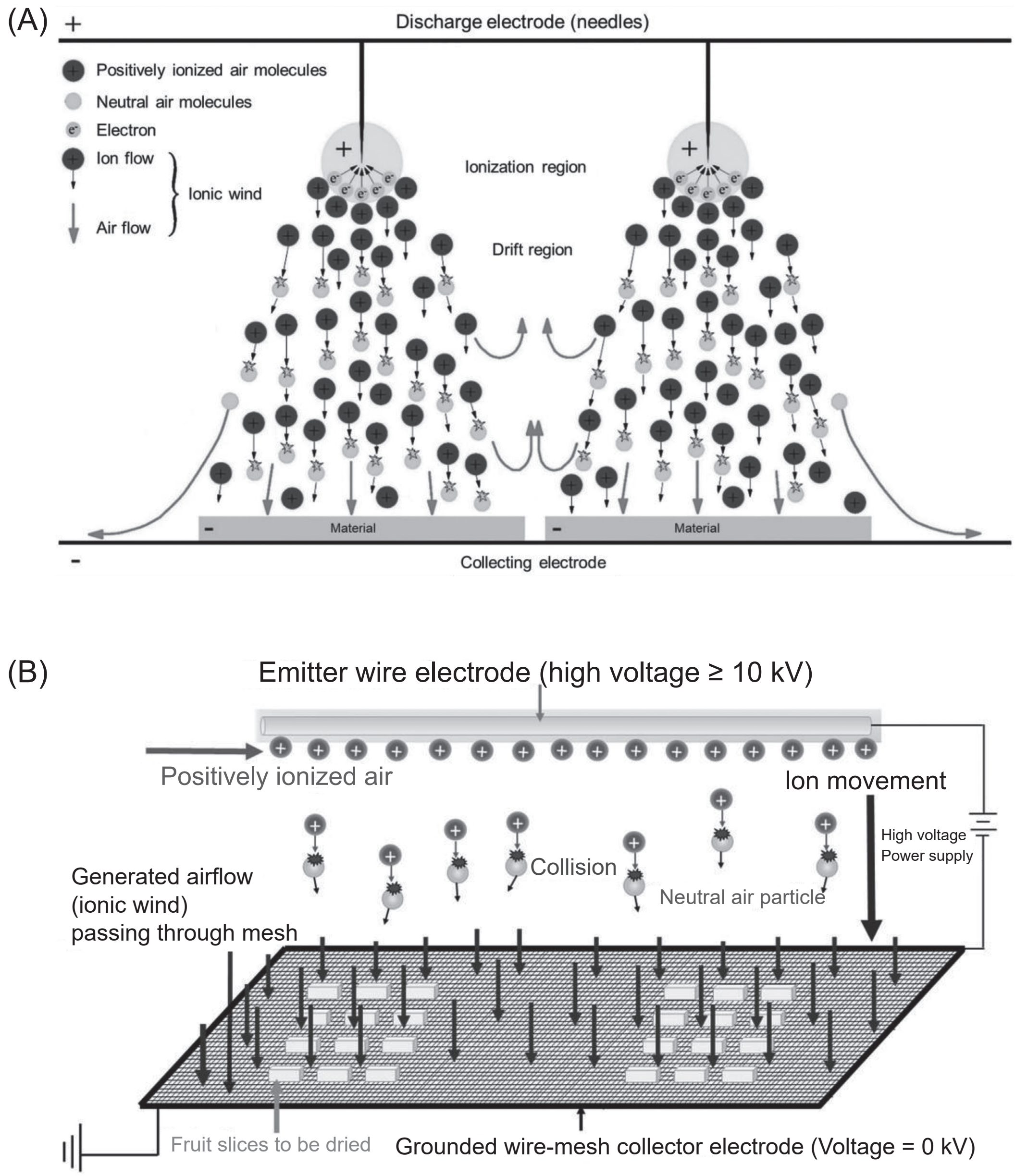


Fig. 1. Schematic illustration of the electrohydrodynamic (EHD) drying principle and system configuration. (A) Principle of ion wind drying: When a high voltage is applied between the emitter and the grounded collector in a gaseous medium, corona discharge occurs near the emitter, resulting in ionization of air molecules. The movement of charged ions toward the collector generates a unidirectional secondary airflow, known as ion wind, which enhances moisture removal from the surface of the material. (B) EHD drying method: The EHD system used in this study consists of a wire-type emitter electrode connected to a direct current (DC) high-voltage power supply and a grounded mesh collector. The material to be dried is placed on the collector surface, where it is directly exposed to the ion wind, facilitating uniform, energy-efficient drying at ambient temperature.

drying surface and enabling consistent moisture removal while preserving product quality.

MATERIALS AND METHODS

Camellia fruit materials and experimental design

To evaluate the performance of the EHD drying system, this study utilized Taiwan-native oil-seed camellia (*C. brevistyla*) fruits as the experimental material. Fresh fruits were harvested from Sanwan Township, Miaoli County, at the end of 2023. Two batches of fruits were collected on October 26 and November 3, respectively. The fresh fruits were stored in a refrigerator at 4℃ prior to testing. The initial moisture content of the fresh oil-seed camellia fruits was approximately 53–55%. Two drying methods were evaluated: the traditional sun drying method (used as the control) and the EHD drying method. The drying temperature for the EHD system was set to 42℃, based on the surface average high temperatures achievable of camellia seeds with the sun-drying method (empirical experience), also the environmental temperature typically used for drying peanuts.

Design and structure of the intelligent EHD dryer

The intelligent EHD dryer developed in this study was designed for agricultural drying applications and evaluated using camellia seeds as a model material. The system comprises two key components: (1) the main drying structure and (2) the intelligent control system.

Main drying structure

The physical components of the EHD dryer include a drying chamber, a hot-air heating unit, an adjustable airflow channel system, an EHD drying field generator, and sensor integration modules. A three-dimensional schematic of the dryer, along with part names and component numbers, is shown in Fig. 2A and detailed in Table 1. System specifications are listed in Table 2.

To improve drying uniformity, the chamber was equipped with a multi-mode airflow system that supports four drying modes: top-down, bottom-up, internal circulation, and static resting (Fig. 2B). This airflow variability allows hot air to be adjusted according to the stacking patterns and material density of the seeds, preventing localized overheating and uneven drying. The system also includes a tempering function- intermittent operation during the drying cycle- to gradually penetrate heat into the material and prevent hull cracking due to overdrying.

The EHD drying field is operated under an applied electric field of 10–40 kV, generating an ion wind that accelerates surface moisture evaporation while enhancing convective heat transfer. This non-thermal mechanism enables rapid moisture removal at lower temperatures, reducing the risk of oil oxidation and preserving the nutritional quality of camellia seeds.

Intelligent control system

The dryer integrates a human-machine interface (HMI) with a programmable logic controller (PLC) to support real-time monitoring and adjustment of key parameters such as temperature, humidity, and airflow (Fig. 3A). Control point distribution for temperature and humidity regulation within the chamber is illustrated in Fig. 3B (Chinese-language interface). Multiple temperature and humidity sensors are embedded at various positions inside the chamber (Fig. 3C) to ensure uniform hot-air distribution. A weight sensor tracks the real-time mass loss of seeds to estimate moisture reduction. At the same time, environmental monitoring modules measure both indoor and outdoor conditions to dynamically optimize drying settings. The system also features one-touch start, automated airflow switching, and heater modulation, allowing the dryer to adapt in real-time to different ambient conditions. Remote monitoring and data logging functions are included to facilitate performance evaluation and operational traceability.

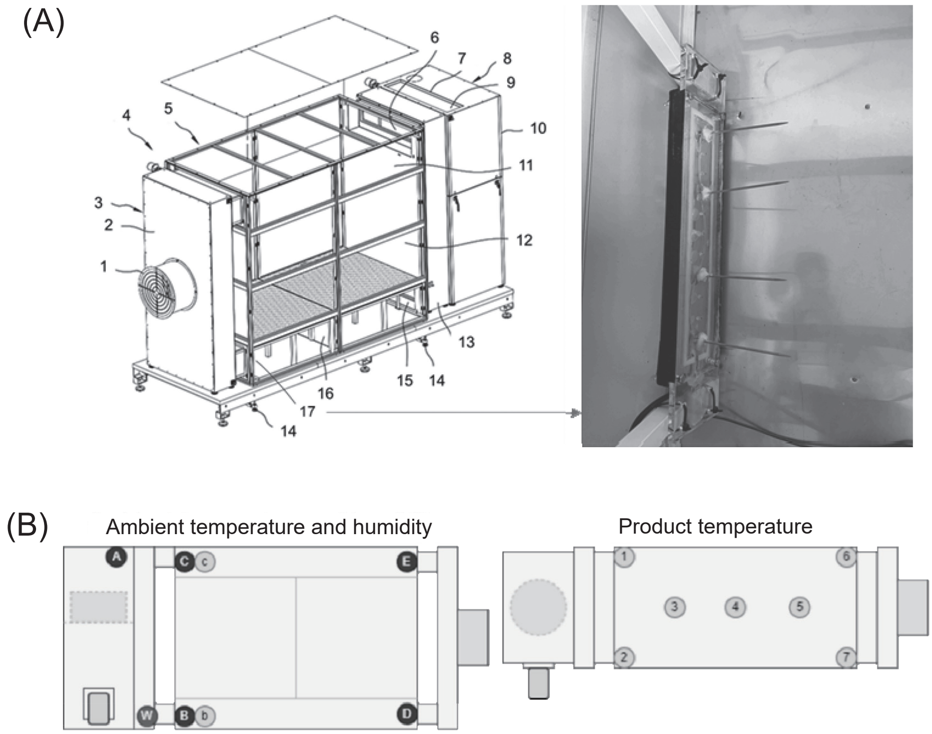


Fig. 2. Structural design and drying modes of the intelligent electrohydrodynamic (EHD) dryer. (A) Three-dimensional schematic of the intelligent EHD dryer, showing the main structural components. The names of components are shown in Table 1. (B) Illustration of four adjustable airflow modes: top-down, bottom-up, internal circulation, and static resting. These airflow configurations enable flexible hot-air routing to enhance drying uniformity based on material distribution. Temperature and humidity sensors are installed at A, B, C, D, E, and W. In addition, temperature sensors are installed at b and c. Numbers 1 to 7 represent the location of the temperature sensor.

Table 1. Component names and part numbers of the intelligent electrohydrodynamic (EHD) dryer.

No.	Component	No.	Component
1	Negative-pressure fan	9	Air inlet valve
2	Second air duct	10	Positive-pressure fan
3	Exhaust system	11	Upper airflow chamber
4	Damper actuator	12	Drying material chamber
5	Drying chamber body	13	First air duct
6	Upper air outlet	14	Weight sensor
7	Air inlet	15	Lower air outlet
8	Heating cabinet (with pressure unit)	16	Lower airflow chamber
		17	Positively ionized air molecules

Sun drying procedure of camellia seeds

The sun drying procedure was designed to simulate traditional practices commonly used by local farmers. Each day, drying was conducted from 8:00 to 17:00. During the first two days of drying, the pericarp of the fresh camellia fruits naturally cracked and was manually removed as needed to extract the seeds, which were then directly exposed to sunlight. From the third day onward, the sun-dried camellia seeds were

Table 2. Specifications of the intelligent intelligent electrohydrodynamic (EHD) dryer.

Item	Specification
Overall dimensions	435.0 cm × 130.5 cm × 215.5 cm (height excluding exhaust pipe and floor scale)
Drying chamber size	245.5 cm × 130.5 cm × 215.5 cm
Maximum stacking depth	Approximately 120 cm
Heating system	Diesel burner with heat exchanger
Fan specifications	Main fan: 1.5 hp; Negative-pressure fan (powered by energy storage system): 1.0 hp (both equipped with inverters)
Drying modes	1. Bottom-blowing/top-suction mode 2. Top-blowing/bottom-suction mode 3. Internal circulation mode 4. Static (resting) mode
Control modes	1. Human-machine interface with smartphone app for remote control 2. Manual/automatic control modes
Material weighing	8-ton floor scale (Load Cell: 2 tons × 4 units)
Sensors	1. Six temperature-humidity sensors 2. Nine temperature sensors (including seven placed within the drying material)
EHD electrodes configuration	Operating at 9 kV, 350 μA; positioned above and below drying layers to enhance ionic wind-assisted convection

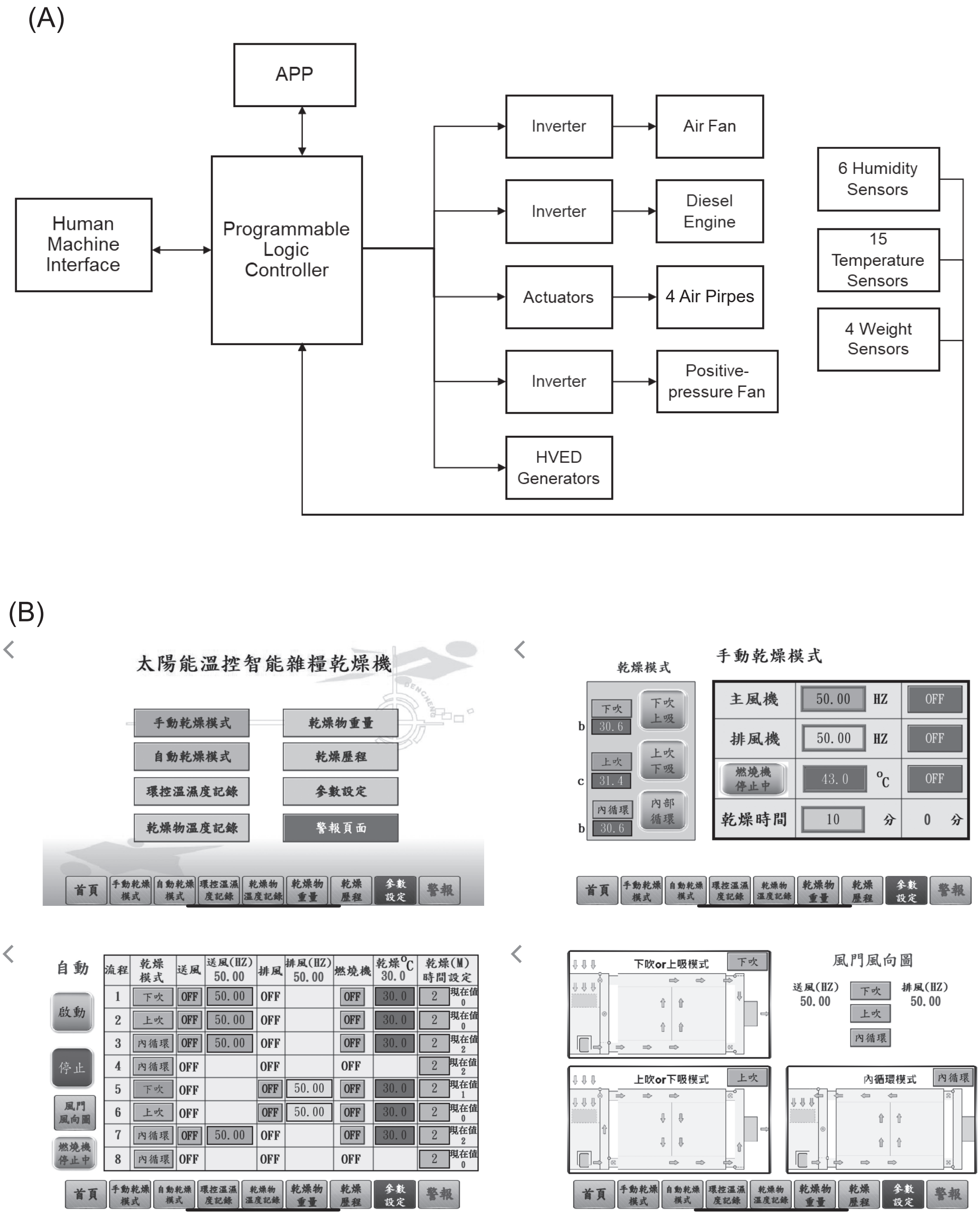
manually turned three times per day—at 10:00, 13:00, and 15:00—to ensure even drying. At 17:00 each day, the seeds were collected and stored in a shaded area at room temperature. The seed surface temperature was recorded daily at 13:00 to reflect the maximum thermal exposure during sun drying. Drying was performed for 8 h per day, except on weekends and days with unfavorable weather, when the seeds were stored indoors.

For the first batch, 3 kg of fresh camellia fruits (initial moisture content: 53.2%) harvested on October 26 were stored at 4℃ until the drying trial began. By the start of sun drying on December 13, the moisture content had naturally dropped to 32.9%. Drying was conducted from December 13 to 26, 2023, for a total of 9 drying days, excluding December 16–17 and 23–24 (weekends), and December 22 (a cloudy, cold day). Sun drying was terminated when the seed moisture content reached 10%. The average midday seed surface temperature during the drying period was 42.0℃.

For the second batch, 3 kg of fresh camellia fruits (initial moisture content: 47.8%) harvested on November 3 were similarly stored at 4℃. By the time sun drying began on January 2, 2024, the moisture content had decreased to 32.9%. Drying continued until January 12, requiring an additional 9 drying days. Drying was not performed on January 6–7 and 13–14 (weekends), during which the seeds were stored indoors. The drying process was terminated when the seed moisture content reached 10%. The average midday seed surface temperature was 46.6℃.

Moisture content determination

The moisture content of camellia seeds was determined using a moisture analyzer (Model MX-50, A&D Company, Limited, Tokyo, Japan). A single dehulled seed was ground into a fine powder using a laboratory grinder. Approximately 0.5 g of the ground sample was evenly spread on the sample pan of the analyzer. The measurement was performed at 105℃ using the automatic end-point detection mode according to the manufacturer's instructions. Each mea-


(A)
APP
Human Machine Interface
Programmable Logic Controller
Inverter
Air Fan
Inverter
Diesel Engine
Actuators
4 Air Pirpes
Inverter
Positive-pressure Fan
HVED Generators
6 Humidity Sensors
15 Temperature Sensors
4 Weight Sensors
(B)
太陽能溫控智能雜糧乾燥機
手動乾燥模式
自動乾燥模式
環控溫濕度記錄
乾燥物溫度記錄
乾燥物重量
乾燥歷程
參數設定
警報頁面
乾燥模式
手動乾燥模式
主風機
排風機
乾燥時間
風門風向圖
下吹or上吸模式
上吹or下吸模式
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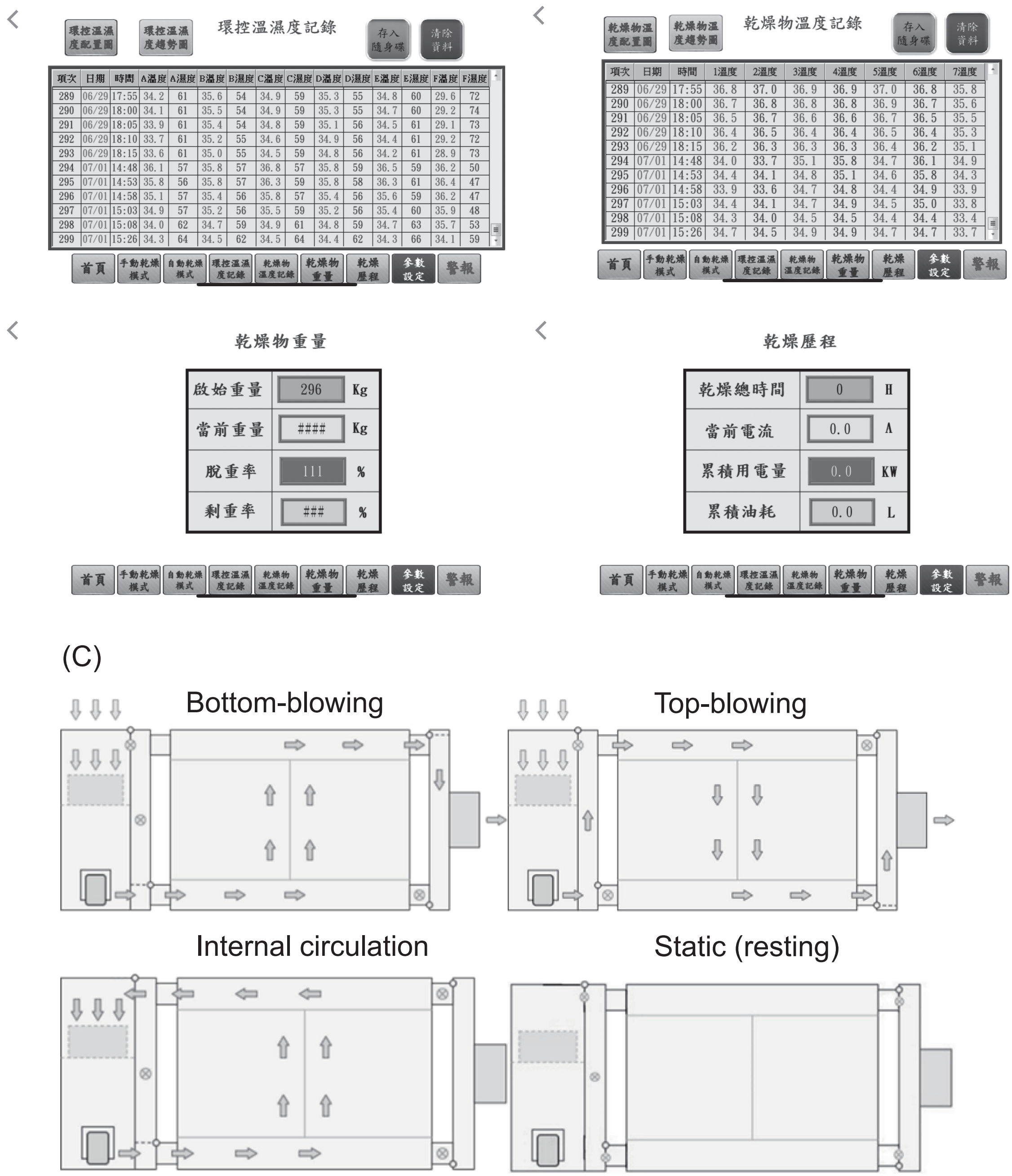

Fig. 3. Intelligent monitoring and control system of the electrohydrodynamic (EHD) dryer. (A) System flowchart of the human-machine interface (HMI) control panel with real-time monitoring functions. (B) Layout of temperature and humidity control points inside the drying chamber (interface display in Chinese). (C) Sensor layout and schematic diagram of internal circulation airflow modes within the chamber, illustrating integration of temperature, humidity, and weight sensors for precision control. HVED: high voltage electrical discharge.

surement was conducted in triplicate, and the average moisture content was calculated and expressed as a percentage on a wet basis.

Oil extraction and quality evaluation

For oil extraction, unroasted camellia seeds were used and pressed with a screw-type oil expeller (Model: SX-TB05, Orin Oil Press, Style International Development Co., Ltd., New Taipei, Taiwan). The obtained crude oil was subjected to centrifugation to remove sediment, and the clear upper oil layer was collected for further analyses. The evaluation indicators included drying time (defined as the time required to reduce the moisture content below 10%), energy consumption (expressed in kWh per kilogram of dried material), oil quality parameters- specifically acid value (AV) and peroxide value (POV)- as well as oxidative stability, measured by the oil stability index (OSI) (Lee *et al*. 2023). AV and POV values are presented as mean ± standard deviation (n = 2 for AV, n = 4 for POV). Statistical analysis was performed using one-way analysis of variance (ANOVA) followed by Tukey's multiple comparison test. Differences were considered significant at $P < 0.05$.

RESULTS AND DISCUSSION

Comparison of drying efficiency between the intelligent EHD dryer and traditional sun drying

To evaluate the effectiveness of the intelligent EHD dryer, its drying performance was compared with traditional sun drying, using camellia fruits as the model material. Key aspects assessed included labor intensity, operational control, and drying efficiency. As summarized in Table 3, the intelligent EHD system exhibited clear advantages in automation, moisture control, and uniformity, while substantially reducing manual labor.

In this study, 90 kg of small-seed camellia fruits (seed diameter: 1–2 cm) were processed in two batches using the intelligent EHD dryer (Fig. 4). Initial seed moisture contents were 51.2% (Batch 1) and 47.3% (Batch 2). The drying process was divided into two stages. The first 24 h employed alternating top-down and bottom-up hot-air flow at 42℃ to promote hull cracking. By the end of this phase, hulls were manually removed, and seed moisture had dropped to

Table 3. Comparison of advantages and disadvantages of different drying methods.

Criteria	Traditional sun drying	Conventional cabinet dryer	Intelligent electrohydrodynamic (EHD) dryer
Weather dependence	High	Not affected	Low
Space requirement	High	High	Low
Labor requirement	High	High	Low
Drying process	Manual turning	Manual turning	No turning required
Drying uniformity	Easily uneven	Easily uneven	High
Material loss during process	Likely	Likely	None
Moisture content monitoring	Manual	Manual	Automated
External energy requirement	None	Required	Required
Loss rate	High	High	Low
Carbon footprint	Low	High	Low
CO_2 emissions	None	High	Low
Drying cost	Medium	High	Low

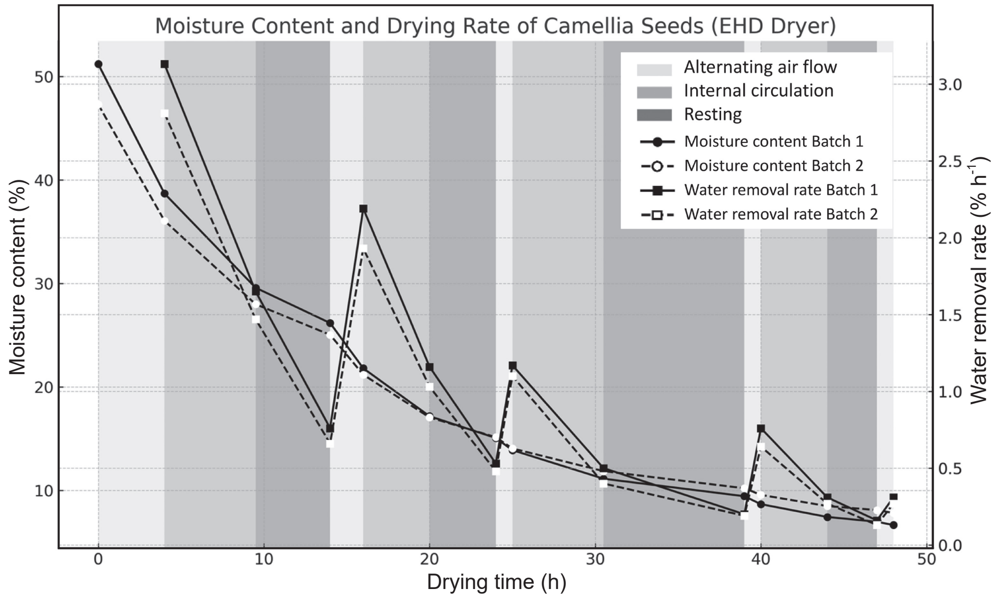

Fig. 4. Drying curves and water removal rates of two batches of camellia seeds using the intelligent electrohydrodynamic (EHD) dryer at 42℃ over 48 h. The drying process alternated between three operational modes- alternating top and bottom airflow with opposite suction, internal circulation, and resting- which are represented by distinct gray-shaded regions. The moisture content of batch 1 decreased from 51.2% to 6.7%, and that of batch 2 decreased from 47.3% to 7.8%. Solid and dashed lines represent the drying profiles of Batch 1 and Batch 2, respectively. Drying rate (% h^{-1}) was calculated for each interval and plotted at the end point of the corresponding drying period. The curves illustrate a typical three-phase drying pattern without an initial lag phase, highlighting reproducibility and consistent drying kinetics under identical EHD conditions.

15.1–11.5%. In the second stage, the system switched to internal circulation with intermittent resting (2 h every 6 h), resuming drying for another 24 h until seed moisture reached 6–8%. Thus, the entire EHD drying process achieved stable dehydration within 48 h, suitable for storage and oil pressing.

Unlike traditional cabinet dryers, which require frequent manual stirring to avoid uneven drying, especially for large-volume materials like camellia seeds, the intelligent EHD dryer eliminates this need. Its programmable airflow-switching system—capable of alternating between vertical airflow and recirculating modes—allowed the seeds to remain static throughout the drying period while ensuring homogenous moisture reduction. Temperature and humidity were well-controlled throughout the process, with monitored values of 41.0 ± 1.1℃ and ± 3% RH variation across six probes and seven embedded seed sensors (Fig. 2B).

The drying curves of the two batches (Fig. 4) demonstrated reproducible behavior under identical conditions. Moisture content declined from 51.2% to 6.7% (Batch 1) and from 47.3% to 7.8% (Batch 2). Three drying phases were observed: a rapid initial drop (0–10 h), a falling-rate phase (10–30 h), and a gradual plateau (30–48 h), consistent with classical drying models. Notably, no evident lag phase was present at the beginning, suggesting that ion wind-assisted airflow in the EHD system effectively removed surface moisture from the outset.

To further quantify drying performance, water removal rate (% h^{-1}) was calculated and plotted against time for both batches (Fig. 4). Both curves showed a sharp initial drying rate followed by a gradual decline, consistent with moisture diffusion limitations as drying progressed. The peak drying rate occurred within the first 2–6 h and reached over 3% h^{-1} for Batch 1 and approximately 2.7% h^{-1} for Batch 2. This pattern aligns well with the observed three-phase drying behavior. Moreover, the drying rate curves revealed minimal variation between batches, confirming consistent system performance and effective airflow management.

The close overlap between the drying curves and drying rate profiles confirms strong batch-to-batch reproducibility, despite minor initial moisture differences. This highlights the robustness of the system's intelligent control, which adapts airflow modes and tempering schedules in real time. Together, these findings validate the practical value of the intelligent EHD dryer for scalable agricultural drying with minimal variability and labor requirements.

Drying behavior of camellia seeds under intelligent EHD dryer

In this study, the drying process of camellia seeds using an intelligent EHD dryer exhibited four distinct cyclic stages, as shown in the moisture content and drying rate curves. Each cycle consisted of three operational phases: directional blowing (either bottom-up or top-down), internal circulation, and a resting period. Notably, the so-called bottom-up and top-down blowing phases involved a paired airflow system with forced air injection from one end and simultaneous suction from the opposite end, i.e., bottom-blowing with top-suction, and vice versa. This design facilitated efficient and uniform moisture removal across the seedbed.

First cycle (0–14 h)

Bottom-up blowing phase (0–4 h): The initial moisture contents were 51.2% (Batch 1) and 47.3% (Batch 2). This phase showed the highest water removal rate (~3.1 % h^{-1}), as surface moisture rapidly evaporated and exited the drying chamber.

Internal circulation phase (4–9 h): With the chamber sealed, vapor could not escape. Moisture within the material is redistributed toward the surface, resulting in a more uniform internal moisture distribution. Although the external moisture removal rate decreased slightly, internal redistribution was significantly enhanced.

Resting phase (9–14 h): A sharp drop in drying rate was observed. At this stage, the surface was relatively dry and hot, while the interior remained moist and cool. Heat is transferred inward, energizing internal water molecules and facilitating their outward diffusion.

Second cycle (14–24 h)

Top-down blowing phase (14–16 h): Reversing the airflow direction (now top-blowing with bottom-suction) eliminated the need for manual turning. Moisture removal accelerated again, with moisture content dropping from ~25% to ~17%.

Internal circulation phase (16–20 h): A slight decline in drying rate occurred, but internal moisture continued to migrate outward, promoting further redistribution.

Resting phase (20–24 h): The drying rate decreased noticeably again, as moisture continued diffusing from the core to the surface.

Subsequent cycles (24–48 h)

The alternating airflow and resting strategy effectively prevented case hardening, a phenomenon where overly dried surfaces hinder internal moisture transfer. This drying protocol maintained a continuous moisture gradient, ensuring connectivity between internal and external moisture phases, and thereby sustaining water migration. By the end of 48 h, final moisture contents reached 6.7% and 7.8% for Batch 1 and Batch 2, respectively.

Compared to conventional drying methods applied to oil-rich seeds such as *C. oleifera*, the intelligent EHD drying system demonstrates distinct advantages in both drying kinetics and operational efficiency. The hot-air drying curve of *C. oleifera* seeds consists of a very short acceleration rate period at the beginning and a long falling rate period, indicating that the drying of *C. oleifera* seeds is mainly controlled by the diffusion of moisture inside the material (Huang *et al*. 2020). This underscores a critical challenge in drying oil-rich seeds: the removal of internal moisture is often hindered by the dense seed structure and high lipid content, which can lead to case hardening and uneven dehydration if not properly managed.

In response to this challenge, Zhang *et al*. (2023) developed a microwave-vacuum drying system specifically designed to enhance internal moisture migration. By combining volumetric heating with reduced pressure, their method accelerated water diffusion from the core to the surface, significantly shortening drying time. However, the study also reported that excessive microwave power could cause seed shell hardening and rupture, ultimately impeding moisture escape and compromising oil quality. Additionally, the system's sensitivity to loading quantity and power settings suggests that precise control is necessary to avoid thermal damage.

In contrast, the intelligent EHD drying system developed in this study offers a non-thermal solution to the same problem. Operating at a low temperature of 42℃, the EHD dryer employs cyclic airflow modes- including directional ion wind, internal circulation, and resting phases- to sustain moisture migration without inducing surface hardening. This approach effectively maintains a continuous moisture gradient, allowing internal water to diffuse outward even under high loading conditions. As a result, the EHD system achieves uniform drying while preserving seed integrity and oil quality, demonstrating its suitability for oil-rich seeds that are prone to diffusion-limited dehydration.

Comparison of pressed oil quality from camellia seeds

To assess the impact of drying methods on oil quality, camellia seeds were dried using either traditional sun drying or the EHD drying method at 42℃ and then analyzed. After hull removal, the kernels were mechanically pressed using a screw-type oil expeller to obtain crude oil. The extracted oils were subsequently analyzed for acid value (AV), peroxide value (POV), and OSI, which are key indicators of oil degradation and oxidative stability.

As shown in Fig. 5, the AVs of oils from two batches of EHD-dried seeds were 0.44 and 0.33 mg KOH g^{-1} oil, respectively, which were significantly lower than those of oils from sun-dried seeds (0.78 and 0.81 mg KOH g^{-1} oil). This suggests that the EHD drying process might be more effective in inhibiting free fatty acid formation. Similarly, the POVs were notably lower in the EHD-dried samples (both 0.25 meq O_2 mL^{-1} oil), compared to 0.99 and 0.49 meq O_2 mL^{-1} oil for sun-dried samples. These results suggest that EHD drying might lead to lower initial oxidation and better oil freshness.

Oxidative stability was further evaluated using the OSI, which measures the induction time (in hours) before rapid oxidation occurs under accelerated conditions. OSI was tested at 110℃, 120℃, and 130℃ with 10 L h^{-1} of air injected into the reaction chamber. As shown in Fig. 6 and Table 4, the OSI values decreased by approximately half for every 10℃ increase in temperature, consistent with a Q_{10}-type thermal oxidation reaction, indicating typical chemical degradation kinetics. The OSI values of oils from EHD-dried and sun-dried seeds were comparable across temperature settings.

Interestingly, a notable difference was observed between the two batches despite only a one-week difference in harvest timing. In the first batch, OSI values at 110℃, 120℃, and 130℃ were approximately 8, 4, and 2 h, respectively. In contrast, the second batch showed higher stability, with OSI values of approximately 12, 6, and 3 h at the same test temperatures. These results suggest that seed maturity at harvest may influence oil quality, with more mature seeds providing higher oxidative stability and oil content (Luo *et al*. 2012). These results suggest that seed maturity at harvest plays a critical role in determining oil quality, with more mature seeds providing higher oxidative stability and oil content. As reported by Luo *et*

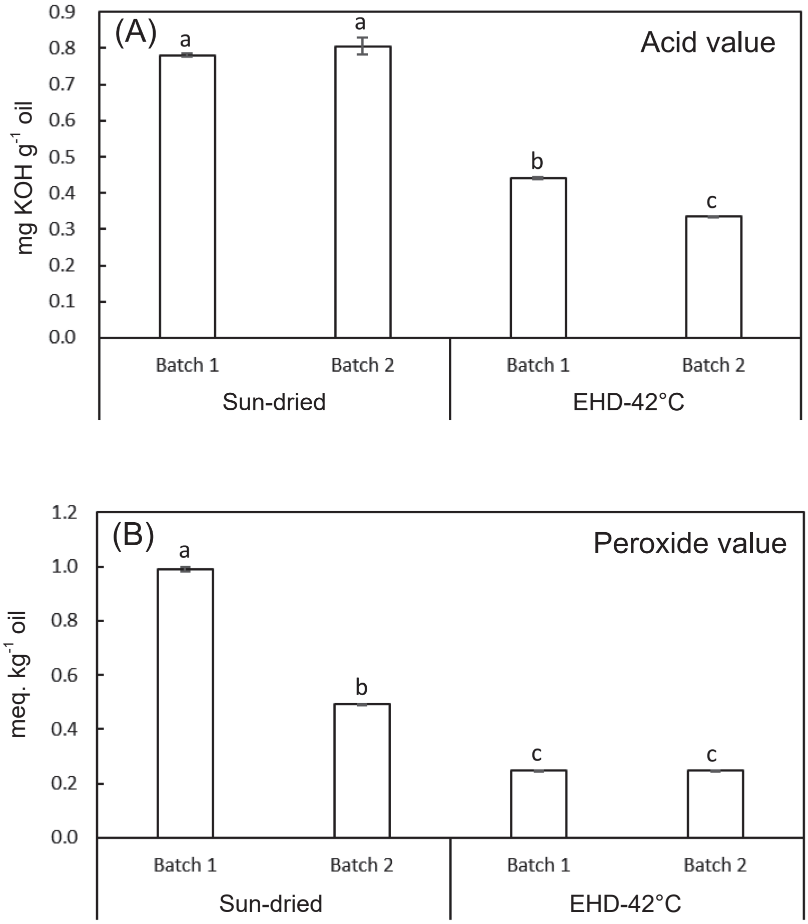

Fig. 5. Acid and peroxide values of oils from camellia seeds dried by sun drying and electrohydrodynamic (EHD) drying. (A) Acid value (AV) was analyzed with duplication; (B) Peroxide value (POV) was conducted with tetraplication. One-way analysis of variance (ANOVA) with Tukey's multiple comparison test (significant $P < 0.05$) was conducted. AV and POV determinations were mean and standard deviation (n = 2 and 4, respectively) are shown on the column, and different letters indicate statistically significant differences.

al. (2012), the contents of unsaturated fatty acids, vitamin E, and β-sitosterol in camellia oil increased significantly as the seeds matured, particularly between October 9 and 24, reaching a peak around October 29. Furthermore, oil extracted from naturally fallen fruits exhibited the highest acid and peroxide values, indicating that over-mature fruits might be prone to hydrolytic and oxidative degradation. Delayed harvesting also reduced spicy and astringent flavors in the oil, while increasing the content of saponins in the press cake. These findings support the importance of optimal harvest timing- just before natural abscission- to ensure maximum oil quality and retention of bioactive compounds.

Sensory evaluations revealed subtle differences in flavor profiles. In the first batch, oils from EHD-dried seeds exhibited a buttery sweetness with mild pungency, whereas oils from sun-dried seeds had a slightly bitter note, moderate sweetness, and a stronger aroma. In the second batch, both drying methods produced oils with a clean, sweet, and fruity char-

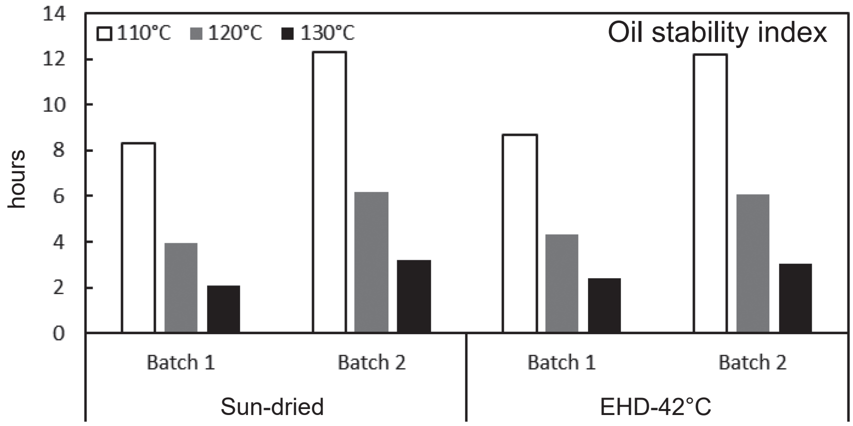

Fig. 6. Oil stability index (OSI) of camellia oil at different oxidation temperatures. OSI values (in hours) of oils extracted from camellia seeds dried by sun drying and EHD drying at 42℃, measured at 110℃, 120℃, and 130℃ under accelerated oxidation conditions. A typical Q_{10}-type degradation pattern was observed. While OSI values were comparable between drying methods, noticeable differences were observed between batches, underscoring the influence of harvest timing on oxidative stability.

Table 4. Oil stability indexes (OSI) and predicted oil stable times at frying temperatures.

		OSI			Prediction[z]	
Drying method	Batch	110℃ (h)	120℃ (h)	130℃ (h)	160℃ (min)	180℃ (min)
Sun dried	1	8.1	4.1	2.0	15.4	3.9
	2	12.2	6.2	3.2	25.1	6.5
EHD at 42℃	1	8.5	4.5	2.3	20.1	5.5
	2	12.2	6.1	3.1	23.0	5.8

[z] Prediction with extrapolation method from OSI values at 110, 120 and 130℃.

acter and no detectable bitterness, suggesting that harvest timing might influence both chemical and sensory attributes.

CONCLUSION

This study evaluated the application of EHD drying for camellia oil seed dehydration and compared its performance with traditional sun drying. Key parameters assessed included drying efficiency, labor intensity, oil quality, oxidative stability, and sensory characteristics of the extracted oil. Results demonstrated that the intelligent EHD dryer significantly improved drying uniformity, reduced drying time, and eliminated the need for manual turning, offering a fully automated and weather-independent solution.

In addition, EHD drying preserved oil quality more effectively, producing oils with lower acid and peroxide values than sun-dried samples, indicating reduced hydrolysis and oxidation. Operating at lower temperatures, EHD drying also minimized thermal degradation, thereby enhancing the retention of bioactive compounds and oxidative stability.

These findings support the feasibility of EHD technology as a novel, non-thermal drying method for camellia seeds and suggest its broader applicability to other agricultural products. Future research should explore optimal combinations of electric field intensity and temperature to further enhance drying performance. The potential to extend this approach to other oil-rich seeds, such as peanuts, sesame, and soybeans, as well as its integration with different drying methods like freeze or hot-air drying, warrants further investigation.

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智慧型電流體動力乾燥機於茶油籽乾燥效率提升之應用

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摘要

曾祥恩、李雅琳、李育賢、林恪群、蘇文瑞。2025。智慧型電流體動力乾燥機於茶油籽乾燥效率提升之應用。台灣農業研究 74(4):541–556。

本研究應用電流體動力 (electrohydrodynamic; EHD) 乾燥技術，使用自行研發之智能型電流體乾燥機，乾燥臺灣原生種短柱山茶 (*Camellia brevistyla*) —— 小果油茶籽，以與傳統日曬法進行比較。評估項目包含油茶籽乾燥效率、冷壓油脂之品質 (酸價 (acid value; AV) 與過氧化價 (peroxide value; POV)) 以及油脂氧化安定性 (oil stability index; OSI)。試驗材料採用 2 批次油茶籽，EHD 乾燥之環境溫度設定於 42℃，此溫度為日曬法可以達到的一般平均高溫。試驗結果顯示，智能型電流體乾燥技術能顯著提升乾燥效率與縮短乾燥時間 (48 h)。相對地，日曬法需 9 d 以完成乾燥。此智能型電流體乾燥方法可以均勻乾燥與減少人工翻堆需求。油脂品質分析結果顯示，電流體乾燥處理的油茶籽壓榨油，其酸價與過氧化值均顯著低於傳統日曬法，顯示其壓榨油品質更佳；油脂氧化安定性 (OSI) 與官能品評之風味特徵則兩種乾燥法相近。綜合評估，電流體乾燥技術應用於油茶籽乾燥，可以提升乾燥效率與其壓榨油之油脂品質，因此具有商業化的應用潛力。

關鍵詞：短柱山茶、油茶籽、油茶籽乾燥、電流體乾燥、油脂品質。

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