

WHITE PAPER

# Drying Medicinal Cannabis

## Why speed is not the objective

A technical assessment of hang drying, freeze-drying and the Glass Pharms controlled drying-and-curing philosophy

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# 1. Executive Summary

Drying is not simply a moisture-removal step. For medicinal cannabis it is a continuation of the microbiological control strategy applied throughout cultivation. Freshly harvested flower contains microorganisms, nutrients and abundant available water. The process must reduce water activity to a stable level without unnecessarily damaging the physical structure or volatile chemistry of the flower.

Traditional hang drying is an agricultural technique whose basic principle predates modern microbiology. Tobacco was being hung in purpose-built barns in Virginia by the 1620s; contemporary practice recognised mould during curing and rot from excessive retained moisture as material hazards.<sup>1</sup>

Freeze-drying addresses the microbiological window in a very different way: the flower is frozen and water is removed by sublimation under vacuum. It can reach a low-water state quickly and can limit thermal cannabinoid decarboxylation. However, cannabis studies have also reported loss of aroma-related volatile compounds and structural damage under some freezing conditions.<sup>23</sup>

Glass Pharms has developed a third philosophy. The process is deliberately not designed to be the fastest possible route to dryness. It integrates approximately two to three weeks of controlled drying and curing, progressively bringing the flower to a stable endpoint of about 0.60  $a_w$  while preserving the time required for post-harvest plant metabolism to subside.

**Fourteen weeks of microbial management during cultivation should not be compromised during the final weeks of production.**

The scientific rationale is straightforward: the microorganisms are already present and the plant itself contains the nutrients they need. The controllable variable is available water. The endpoint is therefore not simply “dry”; it is “cured and microbiologically stable”.

- Hang drying controls the room more directly than it controls the water activity of each flower.
- Freeze-drying reaches microbiological restriction rapidly, but speed and low temperature do not automatically preserve the complete flower profile.
- Curing is not chlorophyll turning into sugar. It includes continuing enzymatic and respiratory processes in harvested plant tissue.
- Incomplete curing can contribute to rising water activity after packing through both moisture redistribution and continued metabolic production of water.
- Glass Pharms treats drying and curing as one controlled post-harvest process, with product stability — not elapsed time — as the endpoint.

<sup>1</sup>U.S. National Park Service. “Tobacco: Colonial Cultivation Methods.” Historic Jamestowne. Records tobacco barns in use by the 1620s, four-to-six-week curing, mould as a curing hazard and spoilage associated with incorrect moisture condition.

<https://www.nps.gov/jame/learn/historyculture/tobacco-colonial-cultivation-methods.htm>

<sup>2</sup>Chassagne-Bercès S, Poirier C, Devaux M-F, Fonseca F, Lahaye M, Pigorini G, Girault C, Marin M, Guillon F. Changes in texture, cellular structure and cell wall composition in apple tissue as a result of freezing. Food Research International. 2009;42(7):788–797. doi:10.1016/j.foodres.2009.03.001. Cryo-scanning electron microscopy and complementary imaging demonstrated ice-crystal-related structural damage under some freezing conditions.

<sup>3</sup>Spadafora ND, Felletti S, Chenet T, et al. The influence of drying and storage conditions on the volatilome and cannabinoid content of Cannabis sativa L. inflorescences. Analytical and Bioanalytical Chemistry. 2024;416:3797–3809. doi:10.1007/s00216-024-05321-w.

## 2. Drying Is a Microbiological Control Process

Cannabis is an agricultural botanical material, not a sterile substrate. Bacteria, yeasts and fungi are naturally present on the plant and in the cultivation environment. Their presence alone does not mean that proliferation will occur. Growth requires the simultaneous availability of the organism, a suitable nutrient source and sufficient available water.

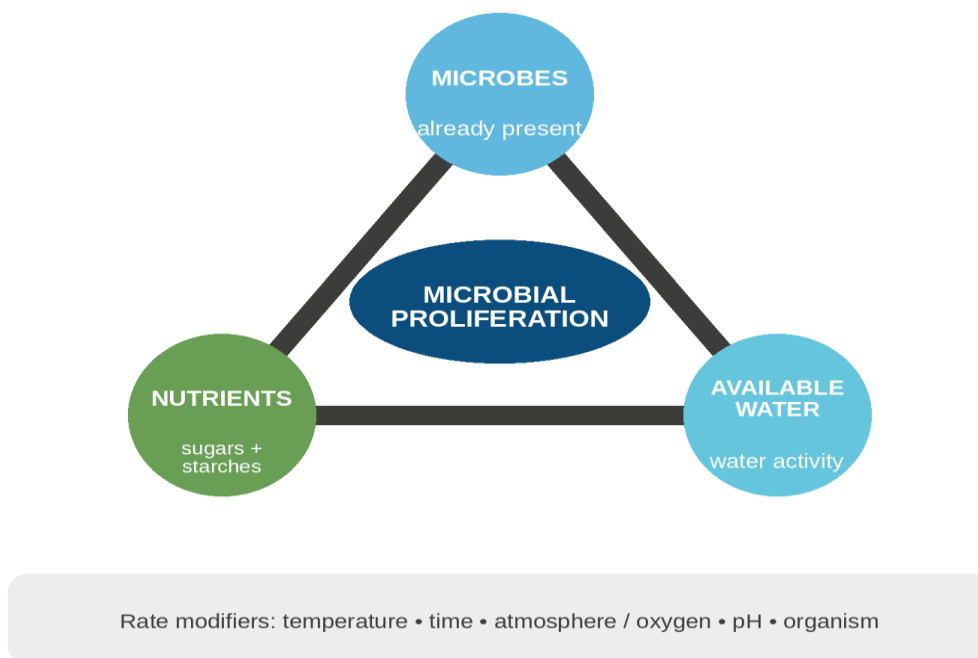


Figure 1. The microbial triangle. Temperature, time, atmosphere/oxygen, pH and microbial species modify growth rate and limits; they do not remove the fundamental requirement for sufficient available water.

For harvested cannabis, two sides of the triangle are intrinsic. Microorganisms are already present, while sugars, starches and other organic compounds provide nutrient substrates. Water availability is therefore the principal post-harvest variable that must be deliberately controlled.

### 2.1 Water activity, not simply moisture content

Water activity ( $a_w$ ) describes the thermodynamic availability of water rather than the total mass of water in the material. ASTM D8197 specifies a recommended range of 0.55–0.65  $a_w$  for dry cannabis flower, with the upper boundary intended to protect against undesirable microbial growth and the lower boundary intended to reduce physical damage from excessive dryness.<sup>4</sup>

There is no universal microbial “on/off” switch at a single  $a_w$ . Most microorganisms require substantially more available water than the most tolerant species. The lower biological boundary is defined by exceptional xerophilic fungi, osmophilic yeasts and other extremophiles; experimentally observed activity extends towards approximately 0.62  $a_w$ , with theoretical limits close to 0.61 under specialised conditions.<sup>5</sup>

Glass Pharms therefore targets approximately 0.60  $a_w$  as a stable endpoint: not because every organism grows above 0.60, but because the process is designed to finish on the restrictive side of the lower biological boundary.

<sup>4</sup>ASTM International. ASTM D8197-22. Standard Specification for Maintaining Acceptable Water Activity ( $a_w$ ) Range (0.55 to 0.65) for Dry Cannabis Flower Intended for Human/Animal Use.

<sup>5</sup>Stevenson A, Cray JA, Williams JP, et al. Is there a common water-activity limit for the three domains of life? The ISME Journal. 2015;9:1333–1351. doi:10.1038/ismej.2014.219.

### 3. Hang Drying: a Seventeenth-Century Process

The tobacco comparison is useful because it is both historical and mechanistic. Tobacco and cannabis are different crops with different intended uses, but both are harvested plant materials in which water must be removed while post-harvest biochemistry continues. Glass Pharms medical cannabis is not intended for smoking; the comparison concerns drying and curing physiology, not route of administration.

The U.S. National Park Service records that tobacco leaves were being hung on lines or sticks in colonial Virginia after 1618 and that tobacco barns were in use by the 1620s. The curing period commonly lasted four to six weeks. Mould was recognised as a danger during curing; tobacco left too damp could rot in transit, while tobacco dried excessively became brittle and commercially unacceptable.<sup>6</sup> A contemporary 1622 etching in Johannes Neander's *Tabacologia* independently shows tobacco leaves hanging to dry on a rack, with other leaves laid under cloths to ferment.<sup>7</sup>



Moyses van Wtenbrouck, *Oorspronkelijke Amerikanen bereiden tabak* (1622), from Johannes Neander's *Tabacologia*. Rijksmuseum, public domain.

**The underlying challenge was understood four centuries ago: too wet invites spoilage; too dry damages the product.**

Modern hang-drying rooms are clearly more controllable than seventeenth-century barns. Temperature, relative humidity and air movement can be monitored and regulated. But the fundamental mechanism is unchanged: the harvested flower is exposed to an atmosphere and water is allowed to diffuse from internal tissues to the surface and then into the surrounding air.

That creates a distinction between environmental control and product control. A dense flower and a small flower do not have the same diffusion path. The surface can dry faster than the centre. Local airflow, load density, flower morphology and starting moisture content all influence the rate of water removal.

A recent post-harvest hemp study found that ambient-air-dried samples had the highest yeast and mould loads among the drying methods examined, while identifying temperature and bioavailable water as primary drivers of microbial growth.<sup>8</sup>

<sup>6</sup>U.S. National Park Service. "Tobacco: Colonial Cultivation Methods." Historic Jamestowne. Records tobacco barns in use by the 1620s, four-to-six-week curing, mould as a curing hazard and spoilage associated with incorrect moisture condition. <https://www.nps.gov/jame/learn/historyculture/tobacco-colonial-cultivation-methods.htm>  
<sup>7</sup>Rijksmuseum. Moyses van Wtenbrouck, *Oorspronkelijke Amerikanen bereiden tabak*, 1622, RP-P-1883-A-6998. Etching/book illustration from Johannes Neander, *Tabacologia*, p.31; depicts tobacco leaves hanging to dry on a rack and leaves laid under cloths to ferment. Public domain. <https://id.rijksmuseum.nl/200277139>  
<sup>8</sup>Postharvest Drying and Curing Affect Cannabinoid Contents and Microbial Levels in Industrial Hemp (*Cannabis sativa* L.). *Plants*. 2025. PMID: PMC11821007.

**Controlling the room is not the same as controlling the water activity of every flower.**

For medicinal production, a prolonged residence time in a high-water-activity state is not intrinsically “gentle”. It is a period during which the microbial triangle remains potentially complete. The post-harvest process must therefore be actively managed so that the control achieved during cultivation is not lost after harvest.

## 4. Freeze-Drying: Fast Stabilisation, Different Trade-offs

Freeze-drying approaches the same problem from the opposite direction. The flower is frozen, pressure is reduced and ice is removed by sublimation. From a microbiological-control perspective the attraction is obvious: the product can move quickly from a high-water-activity state towards conditions in which proliferation is strongly restricted.

Freeze-drying can also reduce heat-driven cannabinoid conversion. In a 2024 comparison of cannabis freeze-drying and tray drying, freeze-drying preserved acidic cannabinoid forms comparatively well.<sup>9</sup>

### 4.1 Cold is not synonymous with gentle

The same study found that freeze-drying caused loss of volatile compounds responsible for cannabis aroma. Of the metabolites significantly different between methods, many aroma-relevant terpenes were lower in the freeze-dried samples. The authors concluded that freeze-drying did not represent an optimal alternative where preservation of the characteristic volatile profile was required.<sup>10</sup>

Independent plant-tissue studies using cryo-scanning electron microscopy have shown that freezing can, under some conditions, cause membrane breakage, cell-wall collapse and tissue damage associated with ice-crystal formation.<sup>11</sup>

The mechanism is plausible. Freeze-drying changes liquid water into ice, then removes that ice under deep vacuum. Ice-crystal formation can alter plant microstructure, while low pressure can promote removal of volatile organic compounds along with water vapour. Process conditions matter, so these findings should not be read as proof that every freeze-drying cycle produces the same outcome; they do demonstrate that low temperature alone is not a guarantee of minimal product impact.

Freeze-drying solves the “wet for too long” problem very effectively. Its potential weakness is that it can solve it too aggressively for a product whose volatile chemistry and physical structure matter.

Freeze-drying should also not be confused with sterilisation. It is fundamentally a dehydration technique. Microbial control still depends on the contamination entering the process, the extent of water-activity reduction and the subsequent storage environment.

### 4.2 The objective is not maximal desiccation

A medicinal flower should not be dried beyond the point required for microbiological stability. Water is part of the physical plant matrix, and the state of that matrix influences how volatile compounds are retained or released. Work on volatile retention in dried carbohydrate systems shows that retention depends on the moisture profile and on the formation of relatively impermeable microregions within the solid matrix.<sup>12</sup>

For cannabis, this matters because many terpenes are highly volatile. Excessive desiccation can increase porosity and internal surface exposure and, particularly under vacuum, can facilitate loss of volatile compounds. The process objective is therefore a controlled quality window: sufficiently low water activity for microbiological stability, while retaining enough water to maintain a plant matrix capable of holding volatile terpenes within the flower's structures and preserving its physical handling characteristics.<sup>13</sup>

9Spadafora ND, Felletti S, Chenet T, et al. The influence of drying and storage conditions on the volatilome and cannabinoid content of Cannabis sativa L. inflorescences. Analytical and Bioanalytical Chemistry. 2024;416:3797–3809. doi:10.1007/s00216-024-05321-w.

10Spadafora ND, Felletti S, Chenet T, et al. The influence of drying and storage conditions on the volatilome and cannabinoid content of Cannabis sativa L. inflorescences. Analytical and Bioanalytical Chemistry. 2024;416:3797–3809. doi:10.1007/s00216-024-05321-w.

11Chassagne-Bercès S, Poirier C, Devaux M-F, Fonseca F, Lahaye M, Pigorini G, Girault C, Marin M, Guillon F. Changes in texture, cellular structure and cell wall composition in apple tissue as a result of freezing. Food Research International. 2009;42(7):788–797. doi:10.1016/j.foodres.2009.03.001. Cryo-scanning electron microscopy and complementary imaging demonstrated ice-crystal-related structural damage under some freezing conditions.

12Flink J, Karel M. Mechanisms of retention of organic volatiles in freeze-dried systems. International Journal of Food Science & Technology. 1972;7(2):199–211. doi:10.1111/j.1365-2621.1972.tb01655.x.

13Spadafora ND, Felletti S, Chenet T, et al. The influence of drying and storage conditions on the volatilome and cannabinoid content of Cannabis sativa L. inflorescences. Analytical and Bioanalytical Chemistry. 2024;416:3797–3809. doi:10.1007/s00216-024-05321-w.

## 5. Curing: What Actually Happens

Curing is frequently discussed as though it were an optional sensory finishing step after drying. That is an oversimplification. Harvested plant tissue does not become biologically inert the instant it is cut. While cells remain viable and enough water and oxygen are available, enzymatic reactions and respiration continue.

### 5.1 Curing is not chlorophyll turning into sugar

Chlorophyll degradation and carbohydrate metabolism occur during the same post-harvest period, but they are different biochemical pathways. Chlorophyll is not converted into sugar.

The more useful model is the metabolism of stored carbohydrates. Tobacco-curing research describes starch being converted into reducing sugars during yellowing and early drying. Those sugars then decline as respiration oxidises them to carbon dioxide and water.<sup>14</sup>

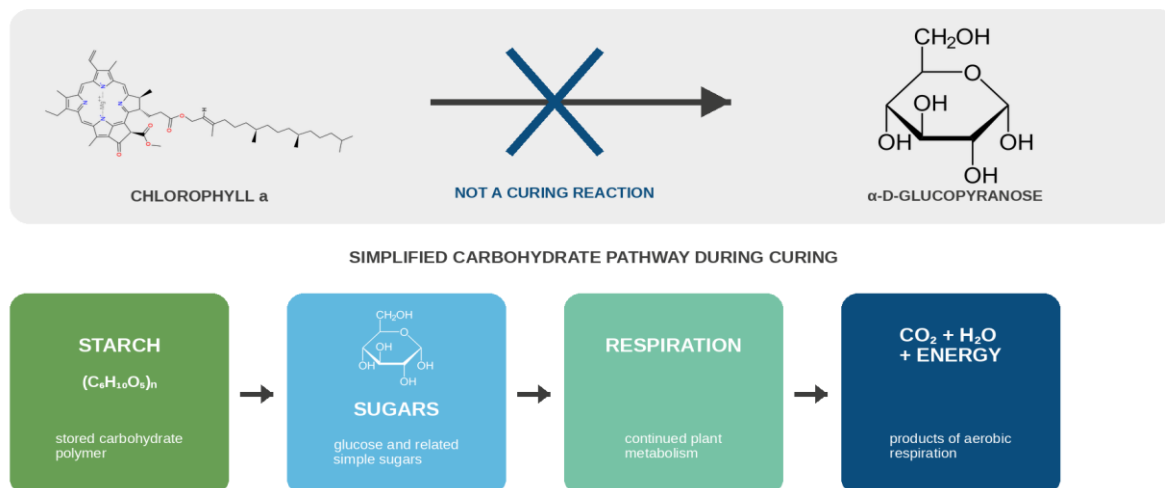


Figure 2. Chlorophyll is not converted into sugar during curing. The relevant pathway is stored starch  $\rightarrow$  sugars  $\rightarrow$  respiration  $\rightarrow CO_2 + H_2O$ .

This is not a tobacco-specific trick. Respiration is fundamental plant physiology. Food and Agriculture Organisation of the United Nations post-harvest guidance notes that respiration continues in plant tissues before and after harvest, drawing on stored sugars and starches as the plant can no longer replace those reserves.<sup>15</sup>

Tobacco provides a particularly useful process analogue because researchers have studied its curing biochemistry in depth. A tobacco-curing process note describes curing as overlapping biological and dehydration phases: while the leaf remains alive, starch hydrolysis and sugar oxidation continue; drying progressively terminates those processes.<sup>16</sup>

### 5.2 Drying and curing overlap

The common sequence “harvest  $\rightarrow$  dry  $\rightarrow$  cure  $\rightarrow$  pack” implies clean boundaries that do not exist biologically. Curing begins while water is being removed. Its rate changes with temperature, oxygen availability and water activity. Eventually the tissue becomes sufficiently dry and senescent that meaningful metabolic activity has effectively ceased.

This creates the central process challenge. The conditions that allow post-harvest plant metabolism to continue can also support microorganisms. A successful medicinal-cannabis process must therefore give the plant enough time to complete the desired transition while continuously preventing available water from creating unacceptable microbial opportunity.

<sup>14</sup>Changes in Moisture and Chemical Composition of Flue-Cured Tobacco During Curing. Tobacco Science. Describes starch conversion to reducing sugars and subsequent respiratory oxidation of reducing sugars to carbon dioxide and water.

<sup>15</sup>Food and Agriculture Organization of the United Nations. Prevention of post-harvest food losses: post-harvest physiology of fresh produce. Describes continuing respiration in harvested plant tissue using stored sugars and starches.

<sup>16</sup>World Bank. Tobacco Curing Process, Annex 3. Describes curing as overlapping biological and dehydration phases, with starch hydrolysis and respiratory oxidation of sugars to carbon dioxide and water while the leaf remains alive.

## 6. Why Water Can “Appear” After Packing

One of the most revealing post-harvest failures occurs when flower appears dry when it leaves the drying room but later develops elevated humidity or mould after packing. To the producer, it can appear that water has “magically appeared” inside the pack.

There are two credible mechanisms, and they can occur together.

### 6.1 Redistribution of water already present

The surface of a flower can dry faster than its dense internal tissues. A sample can therefore feel dry while the whole flower is not yet at equilibrium. Once placed in a sealed pack, water migrates through the flower and into the headspace until a new equilibrium is established. Water activity can consequently rise after packing even though no external water has entered the pack.

Transport can also concentrate water locally. If a packed product leaves a warm, humid environment and is then exposed to a much colder environment, such as a cold aircraft hold, the temperature of the pack and headspace can fall below the dew point and water vapour can condense on internal surfaces or on the flower. Condensation creates local regions with very high water availability even when the bulk product had previously been stable. Temperature fluctuations and condensation in packaged plant material are well recognised as conditions that can promote microbial growth. Transit conditions are therefore part of product stability, not merely a logistics consideration.<sup>17</sup>

### 6.2 Metabolic production of new water

If sufficiently hydrated tissue remains metabolically active, respiration continues. In simplified form, aerobic respiration converts carbohydrate and oxygen into carbon dioxide, water and energy. The water is chemically new: it is produced by metabolism, not merely moved from one part of the flower to another.<sup>18</sup>

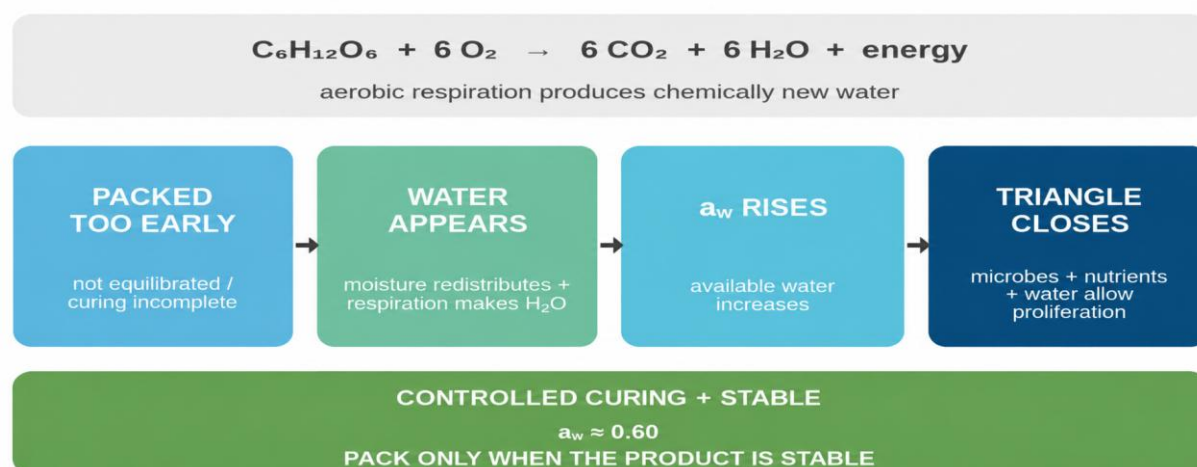


Figure 3. A plausible route to post-pack mould when flower is packed before equilibration and curing are complete.

In an open, controlled curing environment, redistributed moisture and water produced by continuing respiration can still be removed. In a substantially closed package, that water is retained. If local or equilibrium water activity rises sufficiently, the microbial triangle can close again: organisms, nutrients and available water once more coexist.

The mould has not necessarily “arrived” after packing. The conditions that allow organisms already present to proliferate may simply have been recreated.

<sup>17</sup>Linke M, Geyer M. Condensation dynamics in plastic film packaging of fruit and vegetables. Journal of Food Engineering. 2013;116(1):144–154. doi:10.1016/j.jfoodeng.2012.11.026.

<sup>18</sup>Food and Agriculture Organization of the United Nations. Prevention of post-harvest food losses: post-harvest physiology of fresh produce. Describes continuing respiration in harvested plant tissue using stored sugars and starches.

## 7. The Glass Pharms Approach

Glass Pharms developed its post-harvest process around a different objective from either conventional hang drying or freeze-drying. The aim is not to minimise elapsed time. It is to manage water activity throughout the period required for the flower to dry and cure safely.

The process deliberately incorporates approximately two to three weeks of controlled drying and curing. Water is removed gently while the flower proceeds through its post-harvest biochemical transition. Water activity is monitored and progressively brought towards a stable endpoint of approximately 0.60  $a_w$ .

**The duration is not process inefficiency.  
The time is part of the process.**

The proprietary operating parameters are outside the scope of this white paper. The important point is the control philosophy: drying and curing are treated as one integrated process, and the endpoint is defined by the state and stability of the product rather than by a fixed number of hours or by subjective handling characteristics.

### 7.1 Two conditions must be satisfied

- Curing must be substantially complete: the post-harvest metabolic transition has reached a stable endpoint rather than being interrupted simply because the exterior of the flower feels dry.
- Water activity must be stable at the defined target after equilibration, such that subsequent packing does not recreate conditions favourable to microbial proliferation.

This is why Glass Pharms does not regard “fastest drying” as a meaningful quality claim. A process that reaches low  $a_w$  in 24 hours may be microbiologically restrictive but may not preserve the same physical and volatile characteristics. Equally, a process that takes several weeks is not inherently gentle if flower spends an uncontrolled period at water activities or temperatures that support microbial growth.

### 7.2 What the process is designed to protect

- Microbiological control achieved during the cultivation cycle;
- Stable water activity after packing;
- Volatile aroma compounds, including terpenes;
- Physical integrity of the flower and trichomes;
- Cannabinoid profile, avoiding unnecessary thermal transformation; and
- Batch-to-batch repeatability suitable for a medicinal product.

**The design question is not “How quickly can we remove the water?” It is “How do we keep the flower safe while the complete post-harvest process finishes?”**

## 8. Three Philosophies for the Same Problem

The three approaches are best understood as different process philosophies rather than simply different pieces of equipment.

| Dimension               | Traditional hang drying                                            | Freeze-drying                                                                         | Glass Pharms controlled drying + curing                                              |
|-------------------------|--------------------------------------------------------------------|---------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------|
| Process philosophy      | Allow the flower to dry slowly in a controlled room.               | Reach a low-water state rapidly by freezing and sublimation.                          | Control water activity throughout the time required for drying and curing.           |
| Primary control point   | Room temperature, RH, airflow and elapsed time.                    | Freeze-dryer cycle conditions and endpoint.                                           | Product water activity, curing progression and stability.                            |
| Water-removal mechanism | Liquid water diffuses and evaporates to air.                       | Water is frozen, then ice sublimates under vacuum.                                    | Controlled water removal to $a_w$ 0.6 at low temperature                             |
| Microbial-risk window   | Potentially prolonged if $a_w$ falls slowly or unevenly.           | Short: low $a_w$ is reached rapidly.                                                  | Actively managed throughout the curing period.                                       |
| Curing philosophy       | Often treated as a later or separate stage.                        | Can be curtailed by rapid desiccation.                                                | Integral to the drying process; typically 2–3 weeks.                                 |
| Volatile compounds      | Long air exposure can permit losses.                               | Published cannabis data show significant VOC/terpene losses under studied conditions. | Process designed to minimise unnecessary volatile loss.                              |
| Physical structure      | Shrinkage and morphology-dependent variability.                    | Ice/vacuum effects; trichome damage reported by SEM.                                  | Relatively low shrinkage with flower morphology maintained compared to fresh flower. |
| Endpoint                | Frequently time, feel, stem behaviour, moisture or room condition. | Completion of freeze-drying cycle / low residual water.                               | Stable target $a_w$ (~0.60) plus completed controlled curing.                        |
| Principal weakness      | Indirect and variable control of individual flowers.               | Can prioritise speed over whole-flower quality.                                       | Takes time and requires active process control.                                      |
| Core philosophy         | <b>Dry slowly.</b>                                                 | <b>Dry quickly.</b>                                                                   | <b>Dry safely.</b>                                                                   |

Table 1. Comparison of the underlying process philosophies. The Glass Pharms column describes the company's process design intent; public head-to-head performance data against all alternative commercial systems are not presented in this draft.

**Glass Pharms' position is that medicinal cannabis should be released on evidence of product stability, not on the prestige of a particular drying technology or the speed of the cycle.**

## 9. Pharmaceutical Control Strategy

A medicinal-cannabis drying process should be judged by critical quality attributes rather than by the label attached to the technology. The strongest validation programme would demonstrate the complete drying-and-curing trajectory and the stability of the packed product.

### 9.1 Critical measurements

**Water activity trajectory:** Measure  $a_w$  through the process, not only at the end. The critical question is how long product remains within conditions capable of supporting microbial proliferation and whether the final value remains stable after equilibration.

**Within-batch uniformity:** Characterise flower-to-flower and position-to-position variation. A mean value can conceal wetter individual flowers.

**Microbiology:** Trend TAMC/TYMC and relevant specified organisms before drying, during process development and after completion. Drying should not create a late-stage increase in microbial burden.

**Post-pack stability:** Recheck  $a_w$  after packing/equilibration. This directly tests the “water has appeared” failure mode.

**Volatile retention:** Use terpene/VOC profiling to demonstrate what is preserved through the process, particularly monoterpenes that are readily lost.

**Cannabinoid profile:** Track acidic and neutral cannabinoids to identify unwanted thermal or oxidative conversion.

**Physical integrity:** Assess flower morphology, friability and, where useful, trichome structure.

**Organoleptic assessment:** Each batch undergoes organoleptic assessment as part of quality control, including appearance, aroma and physical characteristics. This provides a structured check that the finished flower remains consistent with its expected product profile and can identify deviations that may not be captured by a single analytical measurement.

**Curing progress and endpoint:** Glass Pharms has established chemical methods for following cure progress and defining the endpoint as part of its scientific process development. The detailed markers and acceptance criteria are proprietary, but the principle is that cure completion is demonstrated chemically rather than inferred from elapsed time, stem snap or other folklore.

### 9.2 The release question

The practical release question should be: “Will this flower remain microbiologically stable after it is placed in its final pack?” A satisfactory answer requires more than a single moisture reading. It requires confidence that the flower has equilibrated, curing has reached its intended endpoint and  $a_w$  will remain on the safe side of the microbiological boundary throughout storage.

The endpoint is not “dry enough to pack”. The endpoint is “stable enough to stay safe after packing”.

## 10. Consequences of Poor Microbial Control

### 10.1 Microbial quality is a property of the finished product

Cannabis flower is a botanical material and is not sterile. Microorganisms are naturally present on the plant and in its growing environment. The objective of pharmaceutical microbial control is therefore not necessarily to eliminate every microorganism, but to prevent proliferation and ensure that the finished product complies with a microbiological specification appropriate to its route of administration and patient population.

This distinction is particularly important when considering irradiated cannabis. Irradiation describes a process applied to the product; a microbiological specification describes the quality of the product released to the patient. These are not equivalent measures.

Ionising irradiation can reduce microbial populations by several orders of magnitude, but it should not automatically be regarded as sterilisation. Recent examination of gamma-irradiated cannabis found substantial reductions in microbial load while viable spores of *Aspergillus*, *Penicillium* and *Fusarium* remained recoverable after treatment.<sup>19</sup>

**The clinically relevant question is therefore not simply whether the flower has been irradiated, but what microbiological specification the released batch complies with and what the actual batch results were.**

### 10.2 Microbial standards differ substantially between markets

The permitted microbiological burden of cannabis flower varies substantially between pharmacopoeial categories and jurisdictions. In UK medicinal-cannabis practice, BP/Ph. Eur. 5.1.8B is generally treated as the minimum practical standard for cannabis flower, while the MHRA has stated that inhaled cannabis-based medicinal products should be aligned with the more stringent Ph. Eur. 5.1.4 limits as closely as possible and that increasing finished-product bioburden represents increasing patient risk.<sup>20</sup>

Ph. Eur. 5.1.8C is used as the minimum microbiological standard for imported medicinal cannabis entering the German supply chain. German release documentation routinely identifies 5.1.8C as the applicable microbiological category for imported cannabis flower.<sup>21,22</sup>

<sup>19</sup>Rani M, Kaddoura MJ, Samsatly J, et al. Detection of Mycotoxigenic Fungi and Residual Mycotoxins in Cannabis Buds Following Gamma Irradiation. *Toxins*. 2025;17:528.

<sup>20</sup>Medicines and Healthcare products Regulatory Agency (MHRA). Freedom of Information request on the safety standards for cannabis-based prescription medicines (FOI 22/766). States that inhaled CBPMs should be aligned with Ph. Eur. 5.1.4 as closely as possible and that higher finished-product bioburden increases perceived patient risk.

<sup>21</sup>German medicinal-cannabis release documentation. Certificates of Analysis for Cannabis Flos applying Ph. Eur. 5.1.8C, including ADREXpharma / QSI and Therismos documentation for imported flower.

<sup>22</sup>Punja ZK, Ni L, Lung S, Buirs L. Total yeast and mold levels in high THC-containing cannabis (*Cannabis sativa* L.) inflorescences are influenced by genotype, environment, and pre- and post-harvest handling practices. *Frontiers in Microbiology*. 2023;14:1192035. Reports a Canadian total yeast and mould limit of 50,000 CFU/g, citing Canadian regulatory sources.

| Standard                         | TAMC (CFU/g)   | TYMC (CFU/g)  |
|----------------------------------|----------------|---------------|
| BP 5.1.4                         | $\leq 100$     | $\leq 10$     |
| BP 5.1.8B                        | $\leq 50,000$  | $\leq 500$    |
| BP 5.1.8C<br>(Min German Import) | $\leq 100,000$ | $\leq 10,000$ |
| Canada (Cannabis)                | $\leq 100,000$ | $\leq 50,000$ |

Table 2. Microbial limits comparison (BP and Canada: TAMC and TYMC only). The Canadian row is presented as the maximum cannabis comparator used in this report.

The difference between these standards is not academic. It determines the amount of yeast and mould contamination that may remain in the finished flower. Figure 4 converts the TYMC limits in Table 2 into a direct visual comparison. Dish 1 represents BP 5.1.4, Dish 2 BP 5.1.8B, Dish 3 BP 5.1.8C and Dish 4 Canada (Cannabis). The progression makes the point clearly: as the standard becomes less stringent, the permitted fungal burden increases markedly. For the patient, particularly the immunocompromised patient, these are not equivalent microbiological specifications.

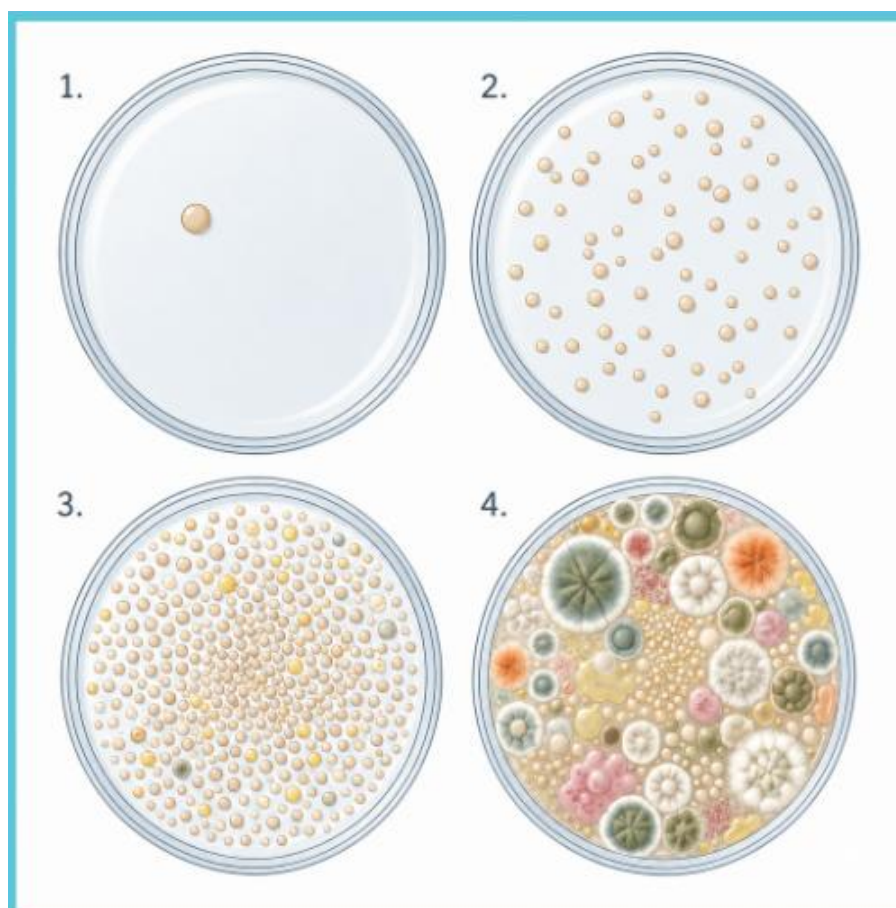


Figure 4. Conceptual illustration of increasing TYMC levels corresponding to Table 2: 1 = BP 5.1.4 ( $\leq 10$  CFU/g); 2 = BP 5.1.8B ( $\leq 500$  CFU/g); 3 = BP 5.1.8C ( $\leq 10,000$  CFU/g); 4 = Canada (Cannabis) ( $\leq 50,000$  CFU/g). The illustration visualises the relative permitted yeast and mould burden and is not intended to depict exact colony counts.

### 10.3 Irradiation is a log-reduction process, not necessarily sterilisation

Irradiation damages microbial DNA and other cellular structures, reducing the number of organisms capable of subsequent replication. Its effectiveness is normally expressed as a logarithmic reduction in viable microbial count.

A one-log reduction is a tenfold reduction. A two-log reduction is a one-hundred-fold reduction. A five-log reduction is a one-hundred-thousand-fold reduction, equivalent to approximately 99.999% reduction in the viable population.

The significance of that reduction depends on the starting burden. If flower contains 10,000,000 CFU/g before treatment, a five-log reduction leaves approximately 100 CFU/g. The treatment has been highly effective, but the product has not been sterilised.

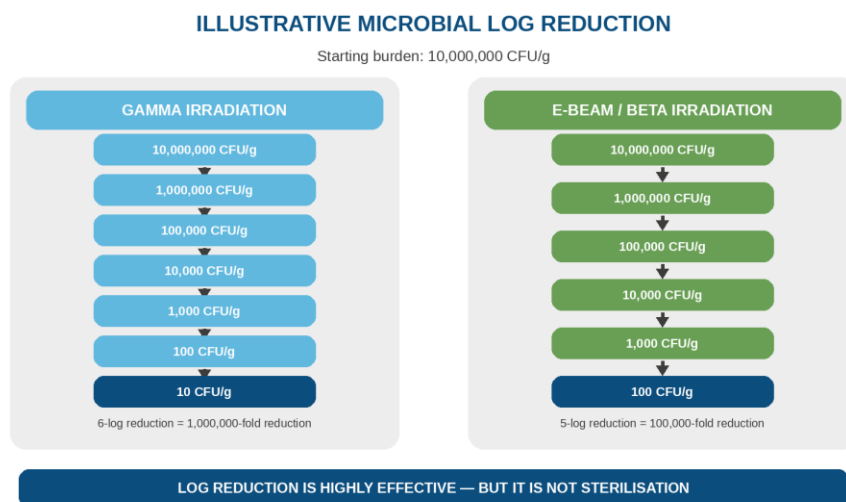


Figure 5. Illustrative six-log reduction for gamma irradiation and five-log reduction for electron-beam (beta) irradiation. Starting from 10,000,000 CFU/g, a six-log gamma reduction leaves approximately 10 CFU/g, while a five-log electron-beam reduction leaves approximately 100 CFU/g. Log reduction is not sterilisation.

### 10.4 Principal irradiation technologies

Three ionising-radiation technologies are principally relevant to cannabis decontamination: gamma irradiation, electron-beam irradiation (commonly described as beta irradiation) and X-ray irradiation. The log reductions shown below are representative ranges demonstrated in cannabis studies rather than universal process specifications; performance depends on dose, organism, initial population, flower geometry, moisture state, packaging and dose distribution.

| Method               | Energy / process                             | Typical demonstrated reduction | Key consideration                                |
|----------------------|----------------------------------------------|--------------------------------|--------------------------------------------------|
| <b>Gamma</b>         | High-energy photons, commonly from cobalt-60 | ~4.5–6+ log                    | Very high penetration                            |
| <b>E-beam / beta</b> | Accelerator-generated high-energy electrons  | ~5–6 log                       | Rapid; lower penetration than gamma              |
| <b>X-ray</b>         | Accelerator-generated X-rays                 | ~4–6+ log*                     | High penetration; smaller cannabis evidence base |

Table 3. Representative microbial reductions demonstrated for ionising irradiation of cannabis. \*For X-ray treatment, published cannabis studies demonstrate complete inactivation across challenge levels from 100 to 10,000 spores/g and also report successful treatment of challenge populations exceeding 1,000,000 spores/g; the evidence base is smaller than for gamma or e-beam irradiation.

In cannabis studies, gamma irradiation reduced total yeast and mould counts by approximately six logs in naturally contaminated material and approximately 4.5 logs in artificially inoculated material. Electron-beam

treatment reduced naturally contaminated commercial cannabis by approximately five logs and achieved reductions of approximately six logs in experimental material at higher treatment doses.<sup>23</sup>

X-ray irradiation at 2.5 kGy rendered *Aspergillus* non-viable at challenge levels of 100, 1,000 and 10,000 spores/g, and the same study also evaluated challenge populations above 1,000,000 spores/g. The cannabis X-ray literature is smaller, so its reduction range should be treated as indicative rather than as a universal process specification.<sup>24</sup>

## 10.5 Irradiation does not remove the microbial triangle

Irradiation reduces the viable microbial population present at the time of treatment. It does not remove the nutrients contained within the flower, it does not permanently control water activity, and it does not necessarily eliminate every viable microorganism or fungal spore.<sup>25</sup>

Some organisms exposed to antimicrobial processing can also be sublethally injured rather than immediately destroyed. Such cells may fail to grow under selective test conditions yet subsequently repair cellular damage and regain viability when environmental stress is removed and favourable conditions return.<sup>26</sup>

**Microbes can remain. Nutrients remain.  
If sufficient available water returns,  
proliferation can return.**

## 10.6 Transport and storage remain microbial-control steps

A satisfactory microbial result immediately after irradiation does not guarantee that the product will remain at that microbial level indefinitely. Drying, curing, packaging, transport and storage continue to determine whether the residual microbial population encounters conditions in which it can grow.

Condensation represents a particular transport risk. Flower leaving a warm or humid environment may subsequently enter a substantially colder environment, such as an aircraft hold. If the product or package falls below the dew point of the enclosed air, water can condense onto plant or packaging surfaces. A relatively small quantity of condensed water can be concentrated into a local microenvironment with a much higher water activity than the average condition of the consignment.<sup>27</sup>

**Warm, humid product → rapid cooling  
→ condensation → locally elevated  
water activity → the microbial triangle  
closes → surviving organisms can  
proliferate**

Irradiation therefore controls microbial numbers at a point in time. It does not provide continuing protection against unsuitable conditions later in the supply chain.

<sup>23</sup>Jerushalmi S, Maymon M, Dombrovsky A, et al. Effects of cold plasma, gamma and e-beam irradiations on reduction of fungal colony forming unit levels in medical cannabis inflorescences. *Journal of Cannabis Research*. 2020;2:12. doi:10.1186/s42238-020-00020-6.

<sup>24</sup>Use of X-ray irradiation for inactivation of *Aspergillus* in cannabis flower. *PLOS ONE*. 2022;17:e0277649. doi:10.1371/journal.pone.0277649.

<sup>25</sup>Rani M, Kaddoura MJ, Samsatly J, et al. Detection of Mycotoxigenic Fungi and Residual Mycotoxins in Cannabis Buds Following Gamma Irradiation. *Toxins*. 2025;17:528.

<sup>26</sup>Sublethally injured microorganisms in food processing and preservation: Quantification, formation, detection, resuscitation and adaptation. Review describing repair and recovery of injured microbial cells under favourable conditions. 2023.

<sup>27</sup>Linke M, Geyer M. Condensation dynamics in plastic film packaging of fruit and vegetables. *Journal of Food Engineering*. 2013;116(1):144–154. doi:10.1016/j.jfoodeng.2012.11.026.

## 10.7 Irradiation can alter the flower

Gamma irradiation is effective against microorganisms but is not necessarily chemically neutral. Hazekamp examined four medicinal-cannabis varieties after 10 kGy gamma irradiation. THC and CBD concentrations were not materially altered, but several volatile terpenes decreased. Reductions were commonly approximately 10% to 20%, with losses of up to approximately 38% for individual compounds; the more volatile monoterpenes were particularly affected.<sup>28</sup>

**Irradiation is an effective microbial-reduction technology, but it should not be assumed to leave every quality attribute unchanged.**

## 10.8 Killing mould does not remove mould

If mould has proliferated through cannabis flower before remediation, irradiation may render much of the fungal population unable to reproduce, but it does not physically remove the fungal material. Hyphae, spores, cell-wall material, proteins and microscopic fragments can remain within the flower.

This distinction matters because fungal allergenicity does not depend upon viability. The US Environmental Protection Agency states that dead mould remains allergenic and that killing mould is therefore not equivalent to removing it.<sup>29</sup>

A product may consequently show a substantially reduced viable fungal count following remediation while still containing the physical residues of previous fungal proliferation. For patients sensitised to mould, this remains a relevant hazard.

## 10.9 Mycotoxins may remain after irradiation

Some fungal species can produce mycotoxins while actively growing. Once these compounds have been produced, reducing the viable fungal population does not necessarily remove the metabolites already present in the flower. A recent study of gamma-irradiated cannabis found that irradiation substantially reduced fungal and bacterial loads but did not achieve complete sterilisation; viable spores from toxigenic fungal genera persisted and residual mycotoxins remained detectable.<sup>30</sup>

<sup>28</sup>Hazekamp A. Evaluating the Effects of Gamma-Irradiation for Decontamination of Medicinal Cannabis. *Frontiers in Pharmacology*. 2016;7:108. doi:10.3389/fphar.2016.00108.

<sup>29</sup>United States Environmental Protection Agency. Mold Course, Chapter 1. Notes that mould can remain allergenic whether dead or alive and that killing mould is not equivalent to removing it.

<sup>30</sup>Rani M, Kaddoura MJ, Samsatly J, et al. Detection of Mycotoxigenic Fungi and Residual Mycotoxins in Cannabis Buds Following Gamma Irradiation. *Toxins*. 2025;17:528.

## 10.10 Immunocompromised patients: the specification matters

For patients with impaired immune function, irradiation status is not the decisive measure of microbial safety. An irradiated product released against a relatively permissive specification can legitimately contain a greater viable microbial burden than a non-irradiated product manufactured and released against a substantially tighter standard.

For immunocompromised patients, the appropriate benchmark should be BP/Ph. Eur. 5.1.4. The relevant information is the microbial specification against which the batch was released, the actual batch results and the absence of relevant specified organisms. This is consistent with the MHRA position that inhaled cannabis-based medicinal products should be aligned with 5.1.4 as closely as possible and that increasing bioburden increases patient risk.<sup>31</sup>

**For an immunocompromised patient, “irradiated” should not be used as a surrogate for “microbiologically safer”. Compliance with an appropriately stringent microbial standard is the relevant criterion.**

## 10.11 Prevention is preferable to remediation

Irradiation is a useful and effective pharmaceutical technology. It can reduce microbial populations by several orders of magnitude and can allow flower produced to one microbiological standard to comply with a more stringent destination-market specification.

It does not make upstream microbial control irrelevant. Irradiation does not necessarily sterilise the flower. Surviving organisms can remain. Fungal biomass and allergens can remain. Mycotoxins can remain. Volatile compounds can be altered. Subsequent environmental conditions can again permit microbial proliferation.

The more robust strategy is therefore to maintain the lowest practicable microbial population throughout cultivation and prevent proliferation during drying, curing, packing, transport and storage. Irradiation may provide an additional reduction where required, but it should not replace that continuous control strategy.

**Irradiation reduces the microbial population. It does not remove the microbial triangle. If microbes remain, nutrients remain and available water returns, microbial growth can return with it.**

<sup>31</sup>Medicines and Healthcare products Regulatory Agency (MHRA). Freedom of Information request on the safety standards for cannabis-based prescription medicines (FOI 22/766). States that inhaled CBPMs should be aligned with Ph. Eur. 5.1.4 as closely as possible and that higher finished-product bioburden increases perceived patient risk.

## 11. Conclusion

The cannabis industry often frames drying as a choice between traditional slowness and technological speed. That is the wrong comparison. The relevant question for medicinal production is which process most effectively controls microbiological risk while preserving the chemical and physical characteristics of the flower and allowing post-harvest biology to finish.

Hang drying is a centuries-old agricultural technique. Modern environmental control improves it, but the process remains dependent on indirect control of water movement through heterogeneous plant material. The historical tobacco literature shows that mould, excess retained moisture and over-drying have been recognised hazards of this approach since the seventeenth century.<sup>32</sup>

Freeze-drying offers rapid restriction of available water and good preservation of acidic cannabinoids, but low temperature does not remove all quality trade-offs. Loss of volatile aroma compounds has been reported in cannabis, while cryo-scanning electron microscopy studies of plant tissue demonstrate that freezing can produce structural damage under some conditions.<sup>3334</sup>

Glass Pharms has therefore developed its post-harvest process around a different objective. Drying and curing are treated as a single controlled transition lasting approximately two to three weeks. Available water is managed towards a stable endpoint of about 0.60  $a_w$  while the flower is allowed time to complete the post-harvest processes that would otherwise continue after packing.



**MICROBES ARE PRESENT.  
NUTRIENTS ARE PRESENT.  
CONTROL THE WATER.**

This philosophy deliberately rejects speed as the primary performance metric. After approximately fourteen weeks spent managing microbial risk during cultivation, the final weeks should not be allowed to reverse that control.



**Drying removes water.  
Curing allows post-harvest biology  
to finish.  
Safe medicinal cannabis production  
must control both.**

On that basis, Glass Pharms regards controlled, integrated drying and curing to a stable water-activity endpoint as the approach best aligned with pharmaceutical-quality medicinal flower: not the fastest process, but the process designed around safety, stability and preservation of the product.

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33Chassagne-Bercès S, Poirier C, Devaux M-F, Fonseca F, Lahaye M, Pigorini G, Girault C, Marin M, Guillon F. Changes in texture, cellular structure and cell wall composition in apple tissue as a result of freezing. Food Research International. 2009;42(7):788–797. doi:10.1016/j.foodres.2009.03.001. Cryo-scanning electron microscopy and complementary imaging demonstrated ice-crystal-related structural damage under some freezing conditions.

34Spadafora ND, Felletti S, Chenet T, et al. The influence of drying and storage conditions on the volatilome and cannabinoid content of Cannabis sativa L. inflorescences. Analytical and Bioanalytical Chemistry. 2024;416:3797–3809. doi:10.1007/s00216-024-05321-w.

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