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POSTHARVEST PRESERVATION OF ORNAMENTAL FLOWERS: ADVANCES IN DRY FLOWER TECHNOLOGY FOR RESIN-BASED VALUE ADDITION

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ABSTRACT

Drying is a critical determinant of floral quality in resin art, influencing both pigment stability and tissue ultrastructure. This review assesses how major floral pigments, such as anthocyanins, flavonoids, carotenoids, and betalains, which control colour retention and aesthetic appeal, are affected by traditional and cutting-edge drying methods. Under less-than-ideal circumstances, pigment degradation is greatly influenced by drying parameters like temperature, duration, and oxygen exposure, which result in discolouration, browning, and loss of vibrancy. Dehydration also causes ultrastructural changes that affect shape fidelity, transparency, and resin compatibility, such as cell wall collapse, vacuolar disruption, and microvoid formation. When compared to conventional air and press drying, comparative analysis shows that desiccant-based, microwave-assisted, and freeze-drying techniques offer better colour intensity and three-dimensional morphology preservation. Furthermore, the optical clarity, mechanical stability, and long-term durability of embedded specimens are significantly influenced by the interaction between dried floral tissues and resin matrices. Treatments applied before and after drying, such as moisture control and pigment stabilisation, further improve quality results. In order to maximise floral preservation for high-value resin art applications, the review identifies current research gaps and highlights the necessity of integrated approaches combining plant physiology, drying technology, and material science.

KEYWORDS: Floral drying, Pigment stability, Tissue ultrastructure, Resin embedding, Color retention

1. INTRODUCTION

Dried flowers also have a significant role in decorative arts and resin works, where they combine natural beauty with durable, easy-to-maintain decorative features that underpin the emergence of a value-added floriculture industry (Mir, 2022; SHAN et al., 2024). They find application in greeting cards, wall decorations, jewellery, paperweights, and epoxy resin works, which address consumer needs for eco-friendly and biodegradable decorative items and year-round availability (Mir, 2022, 2024; SHAN et al., 2024). In resin works, aesthetic considerations are primarily driven by the retention of color and three-dimensional features following dehydration and encapsulation processes. Dehydration methods such as air drying, press drying, desiccant embedding, microwave, and hot air oven drying are specifically used to remove moisture content while retaining the original color, shape, and texture that define the aesthetic and economic value (Gupta et al., 2023; Macchindra & Khandekar, 2025; Mir, 2022). Innovative epoxy resin encapsulation technologies also help to shield dried flowers from dust and insect damage, increase display life, and potentially increase returns for producers and artisans through value addition (Gupta et al., 2023; Oulakh & Rani, 2018). Yet, unsuitable dehydration methods or suboptimal resin conditions could potentially accelerate browning, fading, or disintegration, which could compromise the aesthetic value essential for high-quality resin artworks (Batra, 2015; Verma, 2008).

These issues underscore the importance of understanding pigment chemistry and flower tissue ultrastructure with respect to drying and resin embedding. Flower color is primarily due to anthocyanins, flavonoids, and carotenoids, whose stability is greatly affected by temperature, pH, and oxidation conditions during dehydration and storage (Sumera et al., 2025; Verma, 2008; Zhao & Tao, 2015). Optical analyses indicate that petal color is determined not only by the type and number of pigments, but also by petal thickness, inhomogeneity, and epidermal cell shape and distribution, which regulate light backscattering, saturation, and brightness (van der Kooi et al., 2016; Zhao & Tao, 2015). Stresses due to heat and other factors can cause extreme changes in pigment composition and spectral reflectance without necessarily decreasing visual conspicuousness, which highlights the complexity of color vision after processing (Narbona et al., 2025). Based on these considerations, this review seeks to (i) compile drying and preservation methods applicable to resin embedded botanicals, (ii) discuss the relationship of pigment chemistry and petal ultrastructure to color retention and tissue preservation, and (iii) determine processing methods and research needs for maximizing the quality of dried flowers in resin art.

2. Floral Pigments Relevant to Resin Art Quality

2.1. Classification of Floral Pigments

Flower color and its suitability for resin art, is mainly driven by four major pigment classes: flavonoids, carotenoids, chlorophylls, and betalains (Grotewold, 2006; Miller et al., 2011; Narbona et al., 2021). Flavonoids are the most varied and ubiquitous, and the colored anthocyanins, aurones, and chalcones create red, pink, purple, blue, and yellow colors, while many flavones and flavonols are colorless to the human eye but are strong UV-absorbers, which influence the visible patterns of pollinators and can have subtle effects on visual depth in resin artworks (Adhikary, 2017; Grotewold, 2006; Miller et al., 2011; Narbona et al., 2021). Carotenoids, the second major class, are isoprenoid compounds that create yellow, orange, and some red colors and are found in many ornamental flowers used in crafts, such as chrysanthemum and marigold (Adhikary, 2017; Grotewold, 2006; C. Lu et al., 2021). Chlorophylls, although primarily found in foliage, can remain in sepals and petals and create green or olive colors that can reduce color clarity if not chosen carefully for resin art (Adhikary, 2017; Miller et al., 2011). Betalains, found in a few families, produce strong red-violet betacyanins and yellow betaxanthins, which are highly saturated and desirable when available (Grotewold, 2006; Narbona et al., 2021). Indian art emphasizes that these four classes of pigments are also responsible for color changes during the various stages of flower development, and biochemically driven changes in anthocyanins and carotenoids are responsible for the changes in visual quality, which are relevant to the harvest time for resin embedding (Adhikary, 2017; Ghissing et al., 2025).

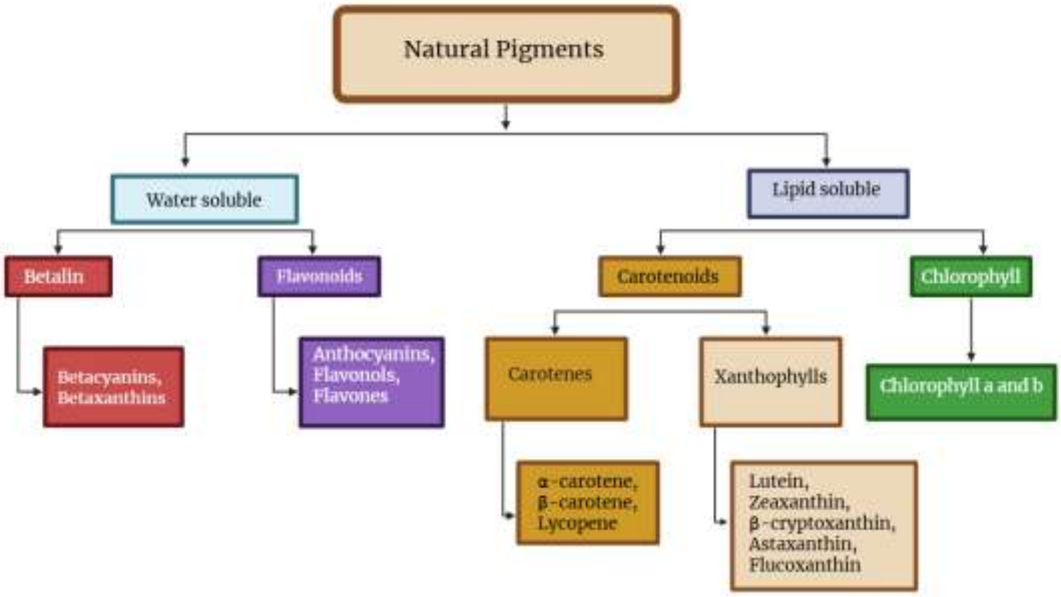

Figure 1. Classification of Floral Pigments

2.2. Pigment Localization in Floral Tissues

The localization of pigments from the organ to the subcellular level is a key factor in the intensity and fixation of flower color after encapsulation in resin. Anatomical observations reveal that anthocyanins and other flavonoids are mainly stored in vacuoles of epidermal cells, carotenoids in chromoplasts of epidermis and mesophyll; this hierarchical organization is responsible for the control of light absorption and re-emission in petal tissues (Adhikary, 2017; Ghissing et al., 2025; Miller et al., 2011; van der Kooi et al., 2016). Optical modeling confirms that pigments localized in the epidermis of the viewing side of the flower produce maximum chromatic contrast and saturation, while the underlying aerenchymatous mesophyll layer acts as a scattering "white backboard" increasing brightness, which is retained when dried petals are embedded in clear resin (De Paola et al., 2025; van der Kooi et al., 2016). Studies on Combretum indicum from India have revealed that anthocyanins are mainly localized in the vacuolar sap of the adaxial epidermis of petals, with additional pigmented vesicles in the cytosol, suggesting active vesicular transport into vacuoles; these epidermal layers also support volatile compound biosynthesis, suggesting a correlation between visible color zones and scented regions attractive for ornamental use (Ghissing et al., 2025). A review of Indian literature on the subject indicates that the internal "sponge" tissues reflect unabsorbed light back through these pigmented layers, so that both pigment concentration and tissue micro-architecture must be taken into account when choosing stages and organs for high impact resin art (Adhikary, 2017).

2.3. Optical Properties of Pigments Affecting Resin Aesthetics

Optical characteristics of flower pigments that affect resin coloration emerge from the combination of wavelength-selective absorption, light scattering, and petal surface microstructure when embedded in a transparent medium. Petals are optically equivalent to stacks of layers in which pigments filter scattered light from deeper layers, and the reflectance spectrum depends on the spectrum of filtered scattered light; reflectance spectrum defines perceived flower color, saturation, and brightness of the conserved flower (van der Kooi et al., 2019; van der Kooi et al., 2016). Anthocyanins, carotenoids, and chlorophylls have different absorption maxima, and the same resin and light source can produce purple, yellow, or greenish colors depending on the prevailing pigment type (Grotewold, 2006; Narbona et al., 2021). The level and distribution of pigments are essential, and low levels of pigments produce pale colors, intermediate levels maximize color contrast, and high levels produce dull, low-contrast colors, as demonstrated by optical modeling and pollinator vision simulation studies(Van der Kooi, 2021; van der Kooi et al., 2016). Pigments localized in the viewing side epidermis produce the highest reflected light modulation and thus the highest color contrast visible through resin, and a highly scattering mesophyll layer acts as a bright "white backboard" that increases petal brightness (De Paola et al., 2025; van der Kooi et al., 2016).

3. Floral Tissue Ultrastructure and Its Role in Resin Embedding

The ultrastructure of floral tissue exerts a strong influence on the behavior of petals and other tissues during fixation, dehydration, and resin infiltration. Petal surfaces are characterized by conical or papillate epidermal cells with a cuticle that can be ridged or perforated by micro-channels controlling wetting, solvent access, and resin infiltration(Cavallini-Speisser et al., 2021). Underlying layers of a variably porous mesophyll with vascular bundles, secretory parenchyma, and intercellular lacunae form a heterogeneous mechanical environment in which differential shrinkage can produce voids and deformations during embedding (Huang & Zhang, 2022; Konarska, 2017). Secretory tissues such as nectaries and glandular parenchyma are characterized by endoplasmic reticulum, plastids, and vacuoles accumulating lipids, phenolics, and polysaccharides, producing local hydrophobic-hydrophilic contrasts controlling resin diffusion and polymerization (Konarska, 2022; Kostryco & Chwil, 2022; Sulborska-Różycka et al., 2022). Research on embedded wood indicates that various acrylic and epoxy resins penetrate cell walls to different depths and modify nanomechanical properties, suggesting that floral materials must also be embedded in specifically selected, diffusively minimal resins and carefully conducted dehydration (Coste et al., 2021).

3.1. Cellular Architecture of Petals and Floral Organs

Petals usually consist of an adaxial and abaxial epidermis surrounding several layers of parenchyma tissue with vascular bundles and secretory areas. The adaxial epidermis usually contains conical to dome-shaped papillae, sometimes with cuticular striations, which increase color saturation and create microtopography that influences capillary fluid movement of embedding media (Cavallini-Speisser et al., 2021; Doody & Moyroud, 2025). Secretory parenchyma is usually present in petals or nectaries, where it is marked by dense cytoplasm, abundant rough and smooth endoplasmic reticulum, mitochondria, and plastids with starch or lipophilic inclusions, indicating high metabolic activity (Huang & Zhang, 2022; Kostryco & Chwil, 2022). Floral nectaries and pseudonectaries are usually composed of a secretory epidermis surrounding several layers of glandular parenchyma with high plasmodesmatal frequency and the presence of sieve tubes and sometimes tracheary elements, facilitating symplastic and apoplastic transfer of substances (Huang & Zhang, 2022; Konarska, 2017). Glandular trichomes and mucilage or resin-secreting idioblasts add to the complexity of cellular types, strength, and permeability in a single type of floral organ (Muravnik et al., 2025; Ribeiro et al., 2021).

3.2. Ultrastructural Components Influencing Shape Retention

Retention of shape in resin-embed floral organs requires the preservation of the cuticle-cell wall, cytoskeleton, and intercellular junction complex responsible for maintaining flower shape. The outer periclinal walls and cuticles of petal epidermal cells are primarily responsible for maintaining both macro- and micro-features such as ridges and papillae; their composition and degree of hydration influence wall stiffness and resistance to deformation during dehydration and infiltration (Doody & Moyroud, 2025; Rongpipi et al., 2019). In mesophyll and secretory tissues, a composite of cellulose microfibrils, hemicelluloses, and pectins maintains a nanocomposite structure that regulates wall porosity and viscoelastic properties, influencing resin diffusion and shrinkage (Rongpipi et al., 2019; Siemianowski et al., 2024). Secretory cells in nectaries and trichomes, characterized by the presence of smooth endoplasmic reticulum, polymorphic plastids, and oil bodies, create regions of varying stiffness and hydrophobicity that can deform or separate if osmotic equilibrium is disturbed (Canaveze et al., 2025; Kostryco & Chwil, 2022). Studies on wood properties indicate that diffusive resins can cause homogenization of stiffness gradients between wall layers, emphasizing the importance of low diffusion systems in preserving floral architecture (Coste et al., 2021).

3.3. Moisture Distribution and Micro-void Formation

In flowers, the distribution of water is necessarily nonuniform, reflecting vascular, mesophyll, nectary, and strong petal transpiration. Petal tissues are composed of water-rich parenchyma, air spaces between cells, and secretory areas where nectar accumulates in intercellular spaces or subcuticular spaces, creating strong local water potentials (Huang & Zhang, 2022; Sulborska-Różycka et al., 2023). Manipulation of petals in experiments shows that transpiration is a major source of floral water, indicating strong evaporative rates and the potential for rapid water loss as dehydration proceeds (Harrap & Rands, 2022). As free water is lost, viscoelastic walls change from expanded to contracted states, and pre-existing lacunae or secretory spaces may expand or merge to form microvoids and cracks that can become trapped bubbles or empty spaces during resin infusion (Konarska, 2017; Kostryco & Chwil, 2022). Investigations of humidity gradients in leaves also indicate that saturation of air spaces decreases from nearly 100% in outer areas to much lower levels near stomata under strong water vapor gradients, consistent with a similar displacement of the saturation front into corolla tissues during processing and the promotion of nonuniform void formation (Wong et al., 2022).

4. Drying Methods Used for Flowers in Resin Art

4.1. Air Drying

Air drying in the shade is the easiest, cheapest process, but prolonged drying causes a gradual breakdown of chlorophyll and anthocyanins, browning and desiccation, thus affecting the translucency of resin casts (Kumar et al., 2024). Roses and chrysanthemum dried in air suffer from maximum moisture loss, longest drying time, and lowest scores for color, texture, and overall acceptability, due to the oxidation of pigments and loss of turgidity of petals (Gurjar et al., 2023). However, mild shade drying helps retain decent color in tough flowers like marigold, which can be used where a slight vintage effect is acceptable in resin art (Rathod et al., 2021).

4.2. Press Drying

Press drying involves flattening the petals between absorbent papers to form thin, low-relief botanical specimens, which can be layered in resin. Capillary action at room temperature removes water, allowing good retention of carotenoids and most flavonoids, though some bright anthocyanins are lost (Bhutani, 1990; Mir, 2022). Three-dimensional ultrastructure is irreversibly flattened, but two-dimensional geometry provides excellent adhesion to resin, minimizing air pockets and optical distortions. Roses, statice, zinnia, and ferns retain natural color when quickly pressed and finished by mild oven support, if necessary, to create archival, paper-like specimens with stable colors for flat resin artworks like bookmarks and coasters (Kher & Bhutani, 1979; Prasad et al., 1997).

4.3. Embedded Drying Using Desiccants

Incorporating blooms into desiccants like silica gel, borax, or sand helps to three-dimensionally support petals rapidly and bind water, thus preventing pigment oxidation and cellular breakdown (Datta, 1997; Raval et al., 2020). Silica gel-embedded roses and carnations demonstrate better color retention, petal density, and least shrinkage with high sensory values for shape and texture over air-dried controls (Gurjar et al., 2023; Singh et al., 2024; Wararkar et al., 2020). In chrysanthemum and rose, embedding in silica gel or sand helps retain carotenoid-based yellows and oranges, resulting in colorful, three-dimensional flowers that are easily visible under clear epoxy resin with less cracking and breaking while casting and finishing (Gupta et al., 2023; Rathod et al., 2021).

4.4. Hot Air Oven and Controlled Thermal Drying

Hot air oven drying at 40-50°C with regulated air flow reduces drying time and enhances quality consistency, but may accelerate pigment degradation if temperature or time are too high (Kumar et al., 2024; Safeena et al., 2006). When done together with silica gel embedding, hot air oven drying results in chrysanthemum and rose flowers with high color scores, minimal shrinkage, and robust petal strength, ideal for bearing resin jewellery and paperweights (Gurjar et al., 2023). However, if done over high temperatures or for longer periods, increased browning and textural brittleness result, indicative of vacuole and cell wall damage; hence, careful optimization of drying protocols is essential for preserving flower brilliance in anthocyanin-rich varieties (Rathod et al., 2021).

4.5. Advanced Drying Techniques

Modern drying methods microwave-assisted drying, freeze drying, and combined infrared hot air drying seek to "lock in" the natural pigments and microstructures before oxidative degradation (Kumar et al., 2024; Mir, 2022). Microwave drying with silica gel embedding is very rapid and results in excellent color and form retention in marigold, gerbera, and rose flowers, with low volume shrinkage, ideal for high-gloss, high-definition resin artworks (Rathod et al., 2021; Singh et al., 2024). Floral freeze drying, especially with customized chemical pre-treatments, retains statice flower pigments and microstructures so well that flowers remain fresh-looking for years, making them superlative choices for drying and encapsulation (Bindu et al., 2021). These drying methods, although more expensive, provide the best possible combination of pigment retention, ultrastructural integrity, and perceived luxury in resin artworks.

5. Influence of Drying on Floral Pigments

Drying is a process that significantly changes the chemical environment of flower pigments, particularly anthocyanins, flavonoids, and betalains, which play a crucial role in petal color and quality in resin art. The rate of drying, temperature, oxygen exposure, and drying time affect the degradation, browning, and color change of these pigments (Cheok & Ragunathan, 2022; Karasu et al., 2015; J. Lu et al., 2021). Higher temperatures and longer drying times are known to accelerate the degradation of anthocyanins and non-enzymatic browning reactions, while optimal low-temperature drying or advanced drying methods (freeze drying, vacuum drying, heat pump drying, or infrared drying) can preserve the color strength, antioxidant activity, and subtle visual properties of high-quality aesthetic products (Caser et al., 2023; Karasu et al., 2015; Padmanabhan & Parvatam, 2024).

5.1. Pigment Stability During Dehydration

The stability of anthocyanins is known to decrease dramatically with increasing drying temperature and time, with a first-order degradation rate of floral pigments being faster for many colored tissues (ElGamal et al., 2023). Lower temperatures and shorter convective drying times have been found to be associated with higher retention of anthocyanins and phenolics in horticultural products, providing a useful guideline for the dehydration of delicate flower petals in resin art (Méndez-Lagunas et al., 2017). Microwave vacuum drying and freeze drying have been found to preserve total anthocyanins and antioxidant activity better than hot air drying, indicating that mild drying conditions can stabilize molecules of flower pigments while ensuring safe moisture removal (Zhang et al., 2023).

5.2. Colour Retention and Fading Mechanisms

Colour preservation in dried plant tissues is also a measure of pigment composition and tissue integrity, as anthocyanins, flavonoids, and other polyphenols are very sensitive to heat and oxidation during the dehydration process (ElGamal et al., 2023). Convective drying at moderate temperatures (approximately 60-70 °C) can result in a reduction of total anthocyanins but still preserve an acceptable level of colour (Bustos et al., 2018; Méndez-Lagunas et al., 2017). However, at higher temperatures and longer dehydration times, pigment degradation and Maillard reactions contribute to browning and loss of colour intensity, resulting in less attractive, brownish, and duller petals that are less suitable for high clarity resin inclusion (J. Lu et al., 2021; Tan et al., 2022).

5.3. Comparative Pigment Preservation Across Drying Methods

The different drying methods have different trade-offs in pigment preservation, which are more desirable for resin art quality. Freeze-drying is generally the best method for preserving anthocyanins, phenolics, and colour but is more expensive and difficult to process (Abbaspour-Gilandeh et al., 2021; Zhang et al., 2023). Microwave vacuum and ultrasound-assisted vacuum drying are faster drying methods that preserve higher amounts of anthocyanins and colour intensity than conventional hot air drying, making them more desirable for resin art with colourful botanical inclusions (Akcicek et al., 2023). Hot air drying or uncontrolled sun drying, on the other hand, can result in higher losses of anthocyanins, browning, and total colour difference, which are less desirable for aesthetic purposes (J. Lu et al., 2021; Nyawo et al., 2025).

6. Influence of Drying on Tissue Ultrastructure

6.1. Cell Wall Collapse and Shrinkage

Dehydration causes substantial structural changes in flowers due to cell wall collapse and volume reduction. Water removal during the drying process depends on cell wall properties, with shrinkage and porosity being affected by the type of cell wall during convective drying (Joardder et al., 2015). Low drying rates cause high collapse intensity due to high loading of liquid tension, while high drying rates create a stiff surface with a protective shell that prevents collapse (Obataya et al., 2005). Cell wall folding during dehydration prevents high mechanical stress between the cell wall and plasmalemma, with xyloglucan and unesterified pectins increasing to provide tensile strength (Moore et al., 2008).

6.2. Vacuolar Disruption and Pigment Leakage

Loss of vacuolar integrity during drying is critical for anthocyanin retention in flowers. Anthocyanins are stored as anthocyanic vacuolar inclusions (AVIs) via microautophagy, where cytoplasmic anthocyanin aggregates are directly engulfed by the vacuolar membrane (Chanoca et al., 2015). There are three types of AVIs: vesicle-like, rod-like, and irregular, with no membrane surrounding the inclusions, indicating intermolecular association within the central vacuole (Zhang et al., 2006). Tonoplast breakdown during dehydration releases vacuolar anthocyanins into the cytoplasm, leading to pigment oxidation and color deterioration.

6.3. Surface Texture Alterations

Drying methods have a significant effect on epidermal surface morphology and texture quality in preserved flowers. Chemical fixation and critical point drying caused tissue shrinkage of 20-30% depending on the tissue type, while methanol fixation preserved dimensions most consistently with only 8% shrinkage (Talbot & White, 2013). Hexamethyldisilazane (HMDS) chemical drying provided equal surface preservation quality to critical point drying for delicate plant specimens (Bhattacharya et al., 2020). Glycerol substitution methods preserve natural shape, epicuticular wax, and cuticle integrity in delicate specimens (Yuan et al., 2024). Surface texture preservation has a direct effect on resin adhesion and final quality in embedded floral specimens.

7. Implications for Resin Art Quality

7.1. Colour Brilliance and Long-Term Stability in Resin

Drying is a strong factor in pigment retention prior to embedding. Controlled dehydration retards enzymatic browning and hydrolysis of anthocyanins and carotenoids, and the intensity of the color is retained once embedded in resin (Anand et al., 2025). Green solvent extraction analyses of rose and bougainvillea demonstrate that low-temperature drying with low water activity prevents pigment oxidation and retains color intensity (Nabi et al., 2023; Prakash et al., 2024).

7.2. Shape Fidelity and Three-Dimensional Preservation

Resin art requires lifelike floral geometry; drying can cause petals to flatten or preserve three-dimensionality. Moisture gradients cause shrinkage and curling of thin tissues, while slow and uniform drying helps retain original curvature and vein topography, which is later well-defined in resin (Ahmed, 2015). Analyses of porous biopolymer and wood substrates indicate that controlled removal of bound water reduces cell wall collapse and distortion, enhancing shape retention after polymerization (Zelinka et al., 2022). Applying this to flowers, pre-drying that reduces capillary forces and preserves microstructure helps retain lifelike volume, layered petal spacing, and natural silhouette when encapsulated.

7.3. Transparency, Bubble Formation, and Optical Clarity

The presence of residual water in dried flowers can lead to outgassing or vaporization of water during resin curing, forming microbubbles and haze around flower petals. Studies on polymer and hydrogel materials demonstrate that trapped water and refractive index differences contribute to scattering and opacity (Chaudhary et al., 2023; Fang et al., 2023). Insufficient drying can be mitigated by reducing vaporization and improving wetting of tissue by resin, resulting in a smoother resin/flower interface (Xu et al., 2022). When cell walls are properly dehydrated without charring, resin penetration becomes more even, reducing internal voids and increasing the transparency and depth effects of resin artworks (Ahmed, 2015; Zelinka et al., 2022).

7.4. Interaction Between Dried Floral Tissues and Resin Polymers

Dried floral tissues can be considered as a porous biocomposite scaffold for low-viscosity resin infiltration. Research on lignocellulosic materials treated with resin demonstrates that low molecular weight thermosets penetrate cell walls, enhancing dimensional stability and hardness with minimal effects on surface gloss and color (Zelinka et al., 2022). In dried flowers, resin penetration can be used to provide mechanical reinforcement to fragile flower petals, but overpenetration and high exotherm can cause discoloration of light-sensitive flower pigments or harden flower tissues (Coccato et al., 2017). Adjusting resin chemistry and curing conditions according to the drying process can optimize mechanical reinforcement with color retention, producing stable and colorful botanical specimens in resin artworks (Ahmed, 2015).

8. Pre- and Post-Drying Treatments to Enhance Resin Compatibility

8.1. Pigment Stabilization Treatments

Pre-drying chemical treatments improve anthocyanin stabilization during flower dehydration through pH adjustment and antioxidant shielding. Silica gel drying showed better color retention than conventional borax treatments in flowers such as chrysanthemums, gerberas, and plumerias. Hot air oven drying at 40°C with borax and mixture of silica gel showed maximum weight of dried flowers in carnation varieties (Macchindra & Khandekar, 2025). Acylated anthocyanins in flowers provide natural stabilization of pigments through intramolecular bonding, which shields the flavylium nucleus from nucleophilic attack even at neutral pH conditions, exhibiting better color retention during dehydration (Enaru et al., 2021).

8.2. Surface Sealing and Moisture Locking

Moisture regulation after dehydration prevents rehydration and preserves the structural integrity required for resin compatibility. Glycerin preservation with a 1:2 ratio effectively replaced cellular water with the hygroscopic glycerol, preserving tissue flexibility without brittleness (Macchindra & Khandekar, 2025). Silica gel drying of orchids retained 81-83% moisture loss in 5 days with preservation of cellular structure (Jeevitha & Jadhav, 2020).

9. Analytical Techniques for Evaluating Pigments and Ultrastructure

9.1. Spectrophotometric and Colorimetric Analysis

Spectrophotometric and colorimetric studies are essential for quantitative measurements of flower pigments chlorophylls, carotenoids, and anthocyanins. UV-visible spectrophotometry, often coupled with solvent extraction and TLC, helps detect peaks, absorbance, and bathochromic or hypsochromic shifts, which indicate the degradation or complexation of pigments. Colorimetric measures (Lab*, ΔE CIELAB) help convert spectral information into perceived color differences, which are crucial for resin art. Standardized sampling, solvent selection, and baseline correction enable comparisons between drying methods, including sun drying, oven drying, microwave drying, and desiccant drying (Sarkar et al., 2024).

9.2. Confocal Microscopy and Image Analysis

Confocal laser scanning microscopy (CLSM), using specific fluorescent probes or autofluorescence imaging, documents the spatial distribution of pigments and phenolics in petal tissues at a subcellular level of detail. CLSM analysis differentiates vacuolar pigment accumulation, cell wall-bound flavonoids, and epidermal cell gradients that differentially affect light absorption and specular reflection, allowing quantitative voxel-based intensity analysis. Digital image analysis 3D reconstructions, intensity distributions, and texture analysis correlates micro-local pigment distribution with visual perception of hue and gloss after resin embedding. Simultaneous use of CLSM and spectrophotometry analysis reveals whether pigment loss is chemical or compartmental, providing recommendations for less harsh drying methods for art conservation (Khan et al., 2015).

10. Sustainability and Value Addition Through Resin Art

Resin art that incorporates dried flowers provides a means to add value to plant-based waste and achieve the principles of a circular economy by giving new life to transient flowers through the creation of long-lasting and valuable artworks (Chiocchio et al., 2021). The use of flowers as natural dyes over synthetic dyes also resonates with green chemistry strategies advocated for sustainable flower pigment extraction, where the use of non-toxic solvents and efficient processing methods is encouraged (Anand et al., 2025). On a macro-level, such strategies also serve to shift the focus away from some of the conventional plastic decorative products whose life cycles are associated with high levels of pollution and low recycling rates, underlining the importance of lower primary plastic demand and improved design for recyclability (Kumar et al., 2021). If the artists choose to work with bio-based or recyclable resin materials and sustainably sourced dried flowers, resin art can provide a means to add value to floral by-products while also partially offsetting the environmental impacts associated with synthetic dyes and disposable plastic decorative products (Chiocchio et al., 2021; Lara et al., 2022).

11. Research Gaps and Future Perspectives

Most Indian research on dry flower technology focuses on the value of craftsmanship and entrepreneurship, but very little quantitative information is available on the effect of drying conditions on pigment biochemistry, tissue ultrastructure, and color stability for resin embedding (Parmeet et al., 2022). Microstructural analysis is mostly visual or panel, with little use of SEM, TEM, or image analysis to correlate cellular collapse, porosity, and hardness with subsequent resin infiltration, transparency, and crack formation (Bindu et al., 2021). Similarly, standardized color measurements, accelerated aging, and lightfastness tests adapted to resin-encapsulated floral artworks are largely absent, although these are essential for high-end art sales(Parmeet et al., 2022). While various techniques including air drying, press drying, desiccant drying, microwave drying, and hot air oven drying are employed for the preparation of dried flowers, limited work has been conducted with respect to the application of integrated drying techniques and preservation protocols for aesthetic purposes like resin art (Mir & Kalpanasawant, 2022; Mir, 2022). Future research should combine controlled drying experiments with spectroscopy, microscopy, and aesthetic sensory style assessments to compare cultivars and drying methods for suitability for resin art, and develop Indian, open-access guidelines that synthesize floriculture, material science, and craftsmanship in a human-centered, livelihood-focused approach (Gupta et al., 2023; Parmeet et al., 2022).

12. CONCLUSION

In this review, drying is seen to be a critical enabling technology that spans the fresh floral delicacy and the more robust, valuable resin art, as it is the key factor that determines the pigment stability and tissue ultrastructure that ultimately impact the clarity, color fidelity, and longevity of the embedded botanicals (Gupta et al., 2023). Dehydration studies of chrysanthemums, carnations, statice, and other ornamental flowers have made it clear that a hot air, shade, silica gel, or freeze-drying process, when properly optimized, can preserve desirable characteristics of color, shape, and moderate brittleness, whereas improperly optimized dehydration processes cause accelerated pigment oxidation, cell rupture, and irregular shrinkage, which subsequently appear as dullness, fractures, and air pockets in resin samples (Bindu et al., 2021; Pawar et al., 2025; Wararkar et al., 2025). Indian research on epoxy resin encapsulation has also shown that by properly coordinating dehydration processes with resin viscosity, curing time, and mold geometry, artisans can successfully convert perishable flowers into meaningful, economically valuable objects that can sustain rural livelihoods and flower waste recycling (Gupta et al., 2023). Thus, the convergence of horticultural drying science and artisanal practice provides a human-centered approach to improve both aesthetic and sustainability qualities of resin art (Bindu et al., 2021; Gupta et al., 2023).

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Data availability statement

No new data were created or analysed in this study. Data sharing is not applicable to this article.

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