



RESEARCH ARTICLE

Multivariate analysis of quality traits in dried rose flowers under chemical pretreatments and microwave drying

Deepika Sahu^{1*}, Bharti Sao¹, Amit Dixit², Toran Lal Sahu¹, Jitendra Kumar Sahu¹, Mayank Parihar³, Vishal Tripathi⁴, Bolagam Ravikumar⁴ & Amrita Kumari⁵

¹Department of Floriculture and Landscaping, Mahatma Gandhi Udyaniki Evam Vaniki Vishwavidyalaya, Durg 491 111, Chhattisgarh, India

²Department of Vegetable Science, Mahatma Gandhi Udyaniki Evam Vaniki Vishwavidyalaya, Durg 491 111, Chhattisgarh, India

³Department of Floriculture and Landscaping, College of Agriculture, Odisha University of Agriculture and Technology, Bhubaneswar 751 003, Odisha, India

⁴Department of Horticulture, School of Agriculture, Lovely Professional University, Phagwara 144 411, Punjab, India

⁵Department of Horticulture, Bihar Agricultural University Sabour 813 210, Bihar, India

*Correspondence email - dpkasahu887@gmail.com

Received: 20 January 2026; Accepted: 27 March 2026; Available online: Version 1.0: 19 May 2026

Cite this article: Sahu D, Sao B, Dixit A, Sahu TL, Sahu JK, Parihar M, Tripathi V, Ravikumar B, Kumari A. Multivariate analysis of quality traits in dried rose flowers under chemical pretreatments and microwave drying. *Plant Science Today*. 2026; 13(sp2): 1-7. <https://doi.org/10.14719/pst.13751>

Abstract

Drying often leads to significant deterioration in the visual, structural and sensory attributes of rose flowers, thereby diminishing their ornamental and commercial value. The present study investigated the effects of various pre-drying chemical treatments and microwave drying durations on the postharvest quality of dried roses. A completely randomised factorial design was employed, comprising 12 treatment combinations, including a control. The pre-drying treatments included 0.5 % citric acid, a 1:3 glycerol-water solution and 10 % magnesium chloride, which were combined with three microwave drying durations of 2.5, 3.5 and 4.5 min. Correlation analysis indicated that moisture loss exhibited a strong negative relationship with dry weight ($r = -0.952$) and shrinkage ratio ($r = -0.940$), suggesting that higher water loss significantly reduced structural retention. Conversely, parameters such as texture, colour and shape showed strong positive correlations with each other ($r > 0.98$), emphasising their coordinated maintenance during drying. Brittleness, however, appeared relatively independent of these quality attributes. Principal component analysis (PCA) revealed two major components: PC1, accounting for 83.33 % of the total variance, primarily capturing sensory and structural characteristics, while PC2, explaining 11.21 %, was associated with flower brittleness. Among the treatment combinations, P₂D₁ and P₂D₂, which involved glycerol-water pretreatment followed by microwave drying for 2.5 and 3.5 min, respectively, were most effective in preserving flower quality. These results indicate that glycerol pretreatment, when combined with moderate microwave drying durations, is superior in maintaining the visual, structural and sensory attributes of dried roses, providing a practical approach for enhancing their postharvest performance and commercial value.

Keywords: dried flowers; glycerol; PCA; postharvest quality; *Rosa* spp.; visual evaluation

Introduction

Roses (*Rosa* spp.) are among the most economically important ornamental crops cultivated worldwide and play a major role in the perfume, cosmetic, landscaping and cut-flower industries. Nonetheless, the significant perishability attributed to moisture content levels of 80–90 % restricts their postharvest longevity and commercial adaptability, especially in dry floral uses. Dried ornamental flowers offer advantages over fresh ones, including longer durability and storage stability, year-round availability and longer shelf-life (1, 2). Their flexibility and permanence make them ideal for decorative crafts like potpourri, decorative arrangements and floral segments (3). The dried flower industry is experiencing significant growth globally, driven by an increasing demand for sustainable and enduring decorative items. Nevertheless, despite their significant aesthetic appeal, roses remain underutilised in this field, mainly because of difficulties in maintaining their form, hue and structural soundness post-drying (4).

In order to maintain the visual appeal and marketability of dried rose flowers, there is a growing focus on enhancing pre-drying treatments and drying techniques through scientific investigation. The application of chemical agents like citric acid, glycerol and magnesium chloride has been documented to improve petal flexibility, prevent enzymatic browning and enhance colour retention by stabilising cellular structures (5, 6). Among the various methods of drying, microwave drying stands out as a highly effective technique. It allows for quick dehydration while effectively reducing structural deformation and pigment loss, provided that the drying conditions are meticulously controlled (4). Nevertheless, excessive exposure to microwaves may result in brittleness, shrinkage and discolouration, highlighting the necessity of refining time-temperature protocols.

Traditional drying methods, such as sun and shade drying, have been found to cause considerable losses in both phytochemical content and visual appeal of flowers, leading to growing interest in more controlled and rapid drying techniques (7).

In flowers like *Rosa* spp., improper dehydration and storage further deteriorate both aesthetic and functional attributes. Although methods such as air drying, microwave drying and freeze drying are used, conventional approaches often fail to maintain structural integrity (8, 9). Glycerol-based pretreatments combined with microwave drying have shown promising results in improving dried flower quality. For example, glycerine pretreatment followed by short-duration microwave drying enhances colour retention, texture, moisture balance and shape stability in roses, with similar improvements reported in carnations (10, 11). Despite these advances, quality evaluation is often based on univariate analysis, which may not capture complex trait interactions. Multivariate techniques such as principal component analysis (PCA) provide an effective approach to identify key quality traits and improve comparison of treatments (11, 12).

Recent work demonstrated that 40 % glycerine pretreatment, followed by brief microwave drying, significantly enhances colour, texture, moisture control and shape retention in rose flowers, underscoring the promise of humectant-based preservation strategies (9). Glycerol-based pretreatments have previously shown efficacy in improving dried flower quality in carnations, enhancing traits like colour and texture, suggesting applicability to roses as well (10). Even with progress in postharvest technology, assessing quality traits in dried flowers frequently relies on univariate analysis, which may fail to reflect the intricate interconnections among various sensory, structural and moisture-related factors. In this context, multivariate techniques like PCA serve as an effective method for reducing dimensionality and prioritising traits. PCA allows for the identification of essential quality indicators by condensing variability into a limited number of principal components, thereby enhancing the comparison of treatment combinations (11, 12).

Consequently, this study aims to perform a multivariate analysis of quality characteristics in dried rose flowers that have been exposed to different pretreatment chemicals and varying durations of microwave drying. This investigation seeks to examine the connections between factors, including moisture loss, texture, shrinkage, brittleness and colour, while also identifying treatment combinations that enhance the quality of flowers after drying. The results will offer important perspectives for creating standardised procedures aimed at improving the visual attractiveness, structural integrity and commercial viability of dried roses, thereby supporting the expansion of the Indian dried flower sector.

In view of the challenges in retaining the structural and sensory quality of dried rose flowers, the present study was

undertaken to systematically evaluate the effect of different pretreatments and microwave drying durations on both quantitative parameters (shrinkage ratio, diameter, dry weight, reduction in weight and moisture loss) and qualitative parameters (brittleness, texture, colour and shape). In addition, correlation analysis was applied to understand the interrelationships among traits, while PCA was employed to identify the major quality indicators and the most effective treatment combinations for preserving postharvest quality in dried roses.

Materials and Methods

The experiment was conducted in 2025 at the Department of Floriculture and Landscaping, Mahatma Gandhi Udyaniki Evam Vaniki Vishwavidyalaya (MGUV), Durg, Chhattisgarh, India. Fresh and fully opened rose flowers (*Rosa* spp.) cultivar (*Rosa hybrida* cv. 'Top Secret') were collected early in the morning from the floriculture research farm. Flowers were selected based on uniformity in size, colour and maturity and were free from any pest or disease symptoms. The study involved 12 treatment combinations comprising three chemical pretreatments (0.5 % citric acid, 1:3 glycerol-water and 10 % magnesium chloride) and three microwave drying durations (2.5, 3.5 and 4.5 min), along with a control (no pretreatment). The experiment was conducted in a completely randomised design (CRD) with three replications. Each treatment consisted of five flowers per replication, resulting in a total of 15 flowers per treatment.

The complete list of treatment codes (P_0D_1 – P_3D_3) with their corresponding pretreatment and drying duration is presented in Table 1. Fresh, uniformly matured rose flowers were subjected to four pretreatment conditions before drying. A 0.5 % (w/v) citric acid solution was prepared by dissolving 0.5 g citric acid in 100 mL distilled water and flower stems were immersed for 15 min at ambient temperature, followed by brief air drying. For glycerol treatment, a 1:3 glycerol-water solution was prepared and flower stalks were placed in the solution for 24 hr at room temperature (~25 °C) to facilitate partial replacement of cellular moisture, after which excess surface moisture was removed by gentle blotting. A 10 % (w/v) magnesium chloride solution was prepared in distilled water and flower stems were immersed for 4 hr and lightly drained before drying. Untreated flowers served as the control. After pretreatment, all samples were subjected to microwave drying.

Microwave drying was carried out using a domestic LG microwave oven operating at a frequency of 2450 MHz with an

Table 1. Treatment combinations of pretreatments and microwave drying durations

Treatment	Treatment combination
P_0D_1	Control + drying for 2.5 min
P_0D_2	Control + drying for 3.5 min
P_0D_3	Control + drying for 4.5 min
P_1D_1	Pretreatment with 0.5 % Citric Acid Solution for 15 min + drying for 2.5 min
P_1D_2	Pretreatment with 0.5 % Citric Acid Solution for 15 min + drying for 3.5 min
P_1D_3	Pretreatment with 0.5 % Citric Acid Solution for 15 min + drying for 4.5 min
P_2D_1	Pretreatment with 1:3 Glycerol-Water for 24 hr + drying for 2.5 min
P_2D_2	Pretreatment with 1:3 Glycerol-Water for 24 hr + drying for 3.5 min
P_2D_3	Pretreatment with 1:3 Glycerol-Water for 24 hr + drying for 4.5 min
P_3D_1	Pretreatment with 10 % Magnesium Chloride for 4 hr + drying for 2.5 min
P_3D_2	Pretreatment with 10 % Magnesium Chloride for 4 hr + drying for 3.5 min
P_3D_3	Pretreatment with 10 % Magnesium Chloride for 4 hr + drying for 4.5 min

output power of 900 W. A batch of fifteen uniformly matured rose flowers was placed in a microwave-safe container, heat-resistant glass containers and completely embedded in silica gel (230–400 mesh size), which acted as a drying medium due to its hygroscopic nature, enabling rapid moisture removal while maintaining flower shape and colour. Drying was performed using an intermittent heating method (30-second cycles) to prevent overheating, charring and uneven moisture loss, until the desired drying durations (2.5, 3.5 and 4.5 min) were achieved. After drying, the samples were allowed to cool at room temperature before removal from the silica gel.

Observations recorded

In the present investigation on multivariate analysis of quality traits in dried rose flowers under different pretreatment and drying combinations, both quantitative and qualitative parameters were recorded. The quantitative observations included the diameter of the dry flower (cm), the weight of the dry flower (g), the reduction in total weight of the flower (g), the moisture loss percentage and the shrinkage ratio. These measurements were aimed at evaluating the physical changes and structural alterations in the flowers due to the applied treatments. In addition to these, qualitative parameters such as brittleness, texture, colour and shape were also assessed through visual observation and a 5-point hedonic scale was used to evaluate qualitative parameters. These qualitative traits were essential in determining the aesthetic appeal and market acceptability of the dried rose flowers.

Moisture Loss = $\frac{W_f - W_d}{W_f} \times 100$ (Eqn. 1)

Shrinkage Ratio = $\frac{D_d}{D_f}$ (Eqn. 2)

Multivariate analysis (PCA and correlation)

The experimental data were analysed using analysis of variance (ANOVA), appropriate for a factorial completely randomised design (FCRD). The significance of treatment effects was tested at the 5 % level of significance and critical difference (CD) values were calculated where the F-test was significant. Statistical analysis was performed using Excel Stat software. To explore relationships among PCA was performed based on the correlation matrix, using standardised variables (mean-centred and variance-scaled) (11, 12). Pearsons’ correlation coefficients were also computed to evaluate inter-variable associations (13). Biplots and score plots were

generated to visualise variable loadings and treatment groupings. All multivariate analyses were conducted in Excel using XLSTAT software (version 2024.1). Variables with high intercorrelation and shared loading patterns were interpreted together to understand the underlying data structure.

Results

Physical and sensory quality of dried rose flowers

Significant variation ($p \leq 0.05$) was observed in shrinkage, diameter and dry weight of rose flowers under different pretreatments and drying durations (Table 2). Maximum shrinkage ($p \leq 0.05$) occurred in untreated samples (P_0D_1 , P_0D_3), while minimum shrinkage ($p \leq 0.05$) (1.12) was recorded in P_2D_2 . Glycerol-pretreated flowers (P_2D_1 , P_2D_2) maintained higher diameter and weight compared to controls. Moisture loss was non-significant. Bar charts (Fig. 1) confirm the superiority of glycerol pretreatment with moderate drying. Sensory scores indicated better overall quality in pretreated flowers, particularly under glycerol and magnesium chloride treatments combined with moderate drying durations, whereas untreated samples recorded lower scores for brittleness, texture, colour, and shape (Table 3).

Correlation analysis of quality parameters

Pearson correlation analysis revealed significant interrelationships among physical and sensory quality parameters (Fig 2). Notably, the weight of dry samples exhibited strong negative correlations with moisture loss ($r = -0.95$) and shrinkage ratio ($r = -0.94$), indicating that greater weight reduction is associated with increased dehydration and dimensional loss. Similarly, the shrinkage ratio had strong negative associations with the diameter of dry flower ($r = -0.98$), moisture loss ($r = -0.904$) and shape ($r = -0.95$), highlighting concurrent loss in volume and structure. Sensory traits such as texture, colour and shape were highly positively correlated ($r > 0.98$), suggesting that visual and tactile quality attributes deteriorate together. Brittleness, however, showed weak correlation with other parameters (maximum $r = 0.15$), indicating it behaves independently. Strong correlations among moisture loss, pigment retention and antioxidant compounds have been previously observed in rose drying studies (e.g. ascorbic acid and anthocyanin, $r = 0.84$), supporting our findings of high inter-variable associations (14).

Principal component analysis (PCA)

Principal Component Analysis reduced the datasets’ dimensionality

Table 2. Effect of pretreatments and microwave drying durations on quantitative parameters of rose flowers

	Shrinkage ratio	Diameter of dry flower (cm)	Weight of dry flower (g)	Reduction in weight of flower (g)	Moisture loss (%)
P_0D_1	1.83 ^a	2.57 ^d	5.00 ^{ab}	5.30 ^{cd}	51.3
P_0D_2	1.60 ^c	2.90 ^d	4.56 ^{abc}	5.20 ^{cd}	53.4
P_0D_3	1.85 ^a	2.57 ^d	5.89 ^a	4.20 ^d	41.7
P_1D_1	1.34 ^{fg}	3.85 ^{ab}	4.11 ^{bc}	8.20 ^{ab}	66.7
P_1D_2	1.31 ^g	3.62 ^{bc}	3.89 ^{bc}	8.80 ^a	69.4
P_1D_3	1.69 ^b	2.88 ^d	4.78 ^{abc}	8.10 ^{ab}	62.9
P_2D_1	1.25 ^h	3.78 ^b	3.56 ^{bc}	9.00 ^a	71.7
P_2D_2	1.12 ⁱ	4.18 ^a	3.00 ^c	9.60 ^a	76.1
P_2D_3	1.40 ^e	3.39 ^c	4.22 ^{abc}	7.30 ^{abc}	63.4
P_3D_1	1.37 ^{ef}	3.40 ^c	3.89 ^{bc}	7.50 ^{abc}	65.9
P_3D_2	1.29 ^{gh}	3.78 ^b	3.67 ^{bc}	7.90 ^{ab}	68.3
P_3D_3	1.48 ^d	3.25 ^c	4.56 ^{abc}	6.00 ^{bcd}	56.7

Values are mean of three replications. Means followed by same letter within a column do not differ significantly at $p \leq 0.05$ (DMRT). Moisture loss (%) was found to be non-significant (NS); hence, no DMRT letters are shown in this column.

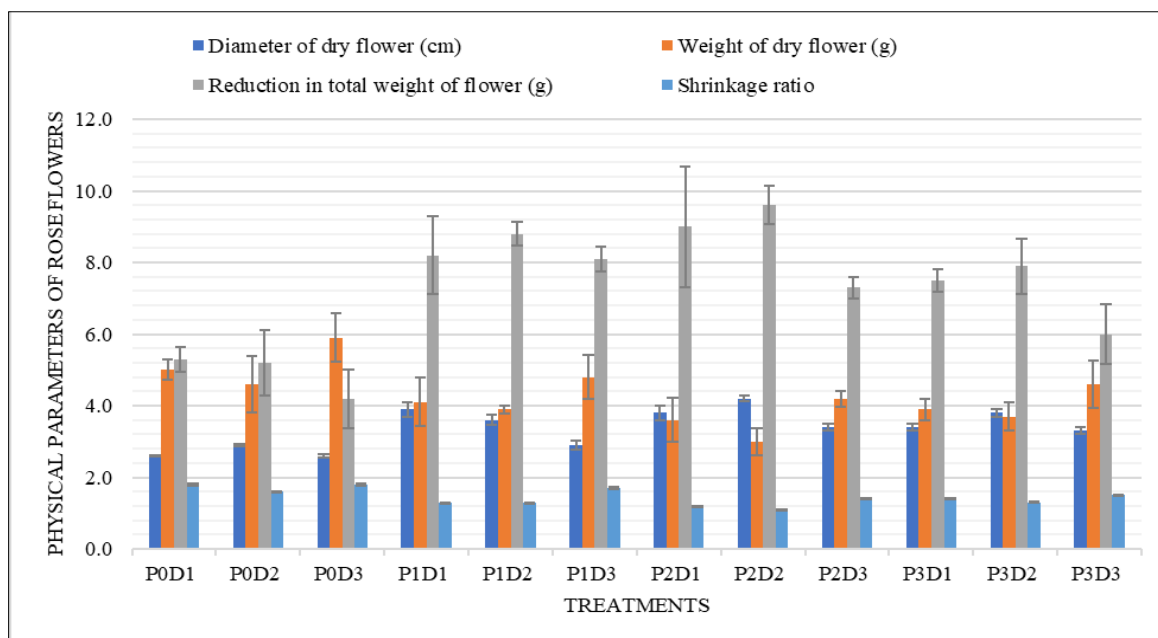


Fig. 1. Effect of pretreatments and microwave drying durations on diameter, weight, reduction in total weight and shrinkage ratio of rose flowers. Values are the mean of three replications. Error bars indicate $\pm$ SEM. Treatments: P₀ = Control (no pretreatment), P₁ = Pretreatment with 0.5 % citric acid solution for 15 min, P₂ = Pretreatment with 1:3 Glycerol-Water for 24 hr, P₃ = Pretreatment with 10 % magnesium chloride for 4 hr; D₁ = drying for 2.5 min, D₂ = drying for 3.5 min, D₃ = drying for 4.5 min.

Table 3. Mean sensory scores of dry rose flowers for qualitative parameters as influenced by pretreatments and microwave drying durations

	Brittleness	Texture	Colour	Shape
P ₀ D ₁	1.5	1.6	1.7	1.7
P ₀ D ₂	2.1	2.1	2.1	2.2
P ₀ D ₃	2.3	1.1	1.2	1.4
P ₁ D ₁	1.1	3.0	3.0	3.0
P ₁ D ₂	3.6	3.7	3.7	4.2
P ₁ D ₃	4.1	1.9	1.9	1.9
P ₂ D ₁	2.6	4.2	4.2	3.8
P ₂ D ₂	3.0	4.6	4.7	4.8
P ₂ D ₃	4.5	2.6	2.7	2.8
P ₃ D ₁	1.9	3.3	3.4	3.4
P ₃ D ₂	3.2	4.0	4.0	4.0
P ₃ D ₃	3.9	2.4	2.4	2.5

Values represent mean scores based on a hedonic 5-point scale (1 = very poor, 5 = excellent) for brittleness, texture, colour and shape of dried rose flowers. Statistical analysis was not applied.

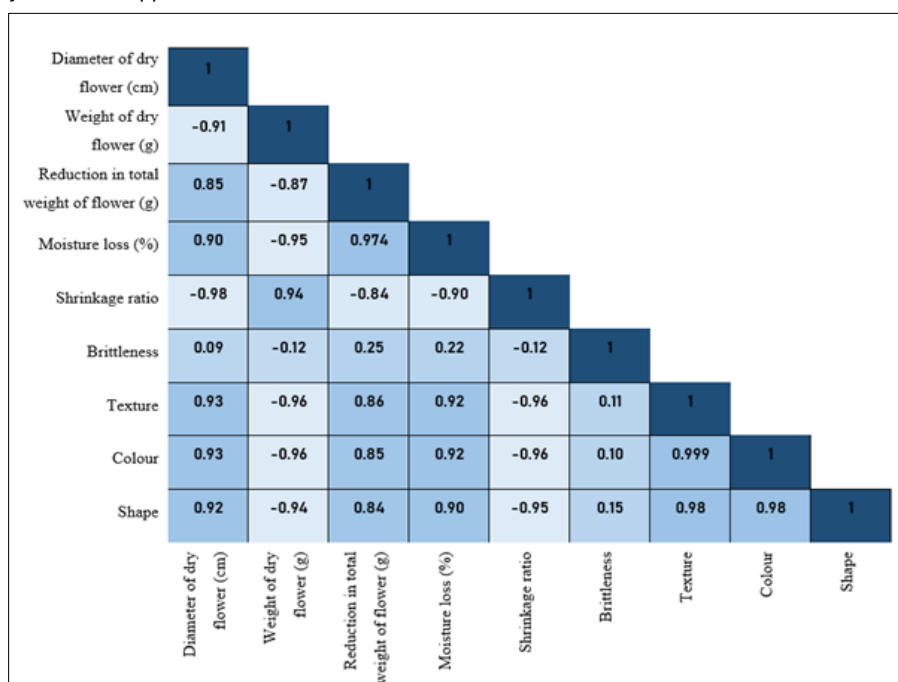


Fig. 2. Correlation matrix heatmap showing Pearson correlation coefficients among quality traits of dried rose flowers under different pretreatment and drying combinations. Stronger correlations are indicated by darker shades; the sign of the coefficient reflects the direction of the relationship.

into nine components, with the first two explaining 94.54 % of the total variance (PC1 = 83.33 %, PC2 = 11.21 %) (Table 4). PC1 was strongly associated with major quality traits, including positive loadings for texture (0.984), colour (0.983), shape (0.971), moisture loss (0.967), diameter of dry flower (0.958) and reduction in total weight (0.917). Negative loadings were observed for dry weight (-0.975) and shrinkage ratio (-0.973), suggesting that PC1 serve as a degradation index. PC2 was defined predominantly by brittleness (loading = 0.980), identifying it as an independent quality dimension. These results are in agreement with findings reported in a previous study, where PCA applied to dried *Gardenia jasminoides* flowers explained a cumulative 84 % of the variance, clearly distinguishing fresh from dried samples based on key quality attributes. This consistency highlights the utility of PCA in identifying critical traits and simplifying the interpretation of complex quality data in dried ornamental flowers (15) (Table 5).

Variable contributions and Cos² values

The percentage contribution of each variable to PC1 ranged from 11.2 % to 12.9 %, indicating a balanced influence of all major traits except brittleness, which contributed only 0.4 %. Conversely, PC2 was shaped almost entirely by brittleness (95.13 %), with negligible influence from other parameters. The Cos² values further validated the structure, with most variables being strongly represented on PC1 (texture = 0.969, colour = 0.966, weight = 0.951, shrinkage = 0.947, shape = 0.943), while brittleness was well-represented only on PC2 (Cos² = 0.960).

PCA scores and treatment grouping

Treatment-specific PCA scores revealed clear differences in quality response. Samples pretreated with 1:3 glycerol-water for 24 hr followed by drying for 3.5 min (P₂D₂) and 2.5 min (P₂D₁) had the

highest positive scores on PC1, indicating superior retention of texture, colour, structural shape and moisture balance. Conversely, untreated control samples dried for longer durations, particularly P₀D₃ (4.5 min) and P₀D₁ (2.5 min), had strongly negative PC1 scores, reflecting poor quality outcomes. High PC2 scores were observed for P₁D₃ (0.5 % citric acid pretreatment + 4.5 min drying) and P₂D₃ (glycerol pretreatment + 4.5 min drying), indicating increased brittleness under prolonged drying. In contrast, P₁D₁ and P₃D₁ (magnesium chloride pretreatment + 2.5 min drying) showed lower brittleness levels with negative PC2 scores.

Contribution of observations to principal components

Observations such as P₀D₃ (28.33 %), P₂D₂ (23.44 %) and P₀D₁ (14.63 %) contributed most to PC1, defining the primary quality variation axis. P₁D₃, P₁D₁ and P₂D₃ were key contributors to PC2, confirming brittleness as a distinct dimension. PC3–PC5 accounted for minor variation and were driven by specific treatments like P₁D₃ and P₃D₃, which influenced weight loss and moisture content moderately.

PCA biplot visualisation

The PCA score plot of PC1 vs. PC2 (94.54 % cumulative variance) displayed clear spatial separation among treatments. P₂D₂ and P₂D₁ were located in the upper right quadrant, aligned with high-quality traits. P₀D₃ and P₀D₁ grouped negatively on both axes, reflecting low quality. P₁D₃ and P₃D₃ were located in the upper left quadrant, associated with high brittleness. This visual confirmation supports the effectiveness of PCA in distinguishing postharvest rose flower treatments based on multidimensional quality attributes (Fig.3).

Discussion

The present study demonstrates that PCA is an effective multivariate

Table 4. Eigenvalues, percentage of variance explained and cumulative variance from principal component analysis (PCA) of quality traits in dried rose flowers.

Principal component	Eigenvalue	Variance explained (%)	Cumulative variance (%)
PC-1	7.500	83.331	83.331
PC-2	1.009	11.207	94.538
PC-3	0.260	2.891	97.429
PC-4	0.134	1.491	98.920
PC-5	0.063	0.698	99.618
PC-6	0.019	0.210	99.827
PC-7	0.013	0.141	99.968
PC-8	0.002	0.024	99.992
PC-9	0.001	0.008	100.000

Table 5. Eigenvectors (principal component loadings) showing the contribution of each quality trait of dried rose flowers to the first five principal components (PC1–PC5).

	PC-1	PC-2	PC-3	PC-4	PC-5
Diameter of dry flower (cm)	0.350	-0.081	-0.116	0.708	0.021
Weight of dry flower (g)	-0.356	0.051	0.007	0.249	0.770
Reduction in total weight of flower (g)	0.335	0.132	0.711	0.033	0.373
Moisture loss (%)	0.353	0.077	0.452	-0.078	-0.236
Shrinkage ratio	-0.355	0.059	0.241	-0.439	0.074
Brittleness	0.063	0.975	-0.199	0.023	-0.038
Texture	0.359	-0.073	-0.197	-0.258	0.163
Colour	0.359	-0.079	-0.212	-0.282	0.155
Shape	0.355	-0.031	-0.309	-0.299	0.393

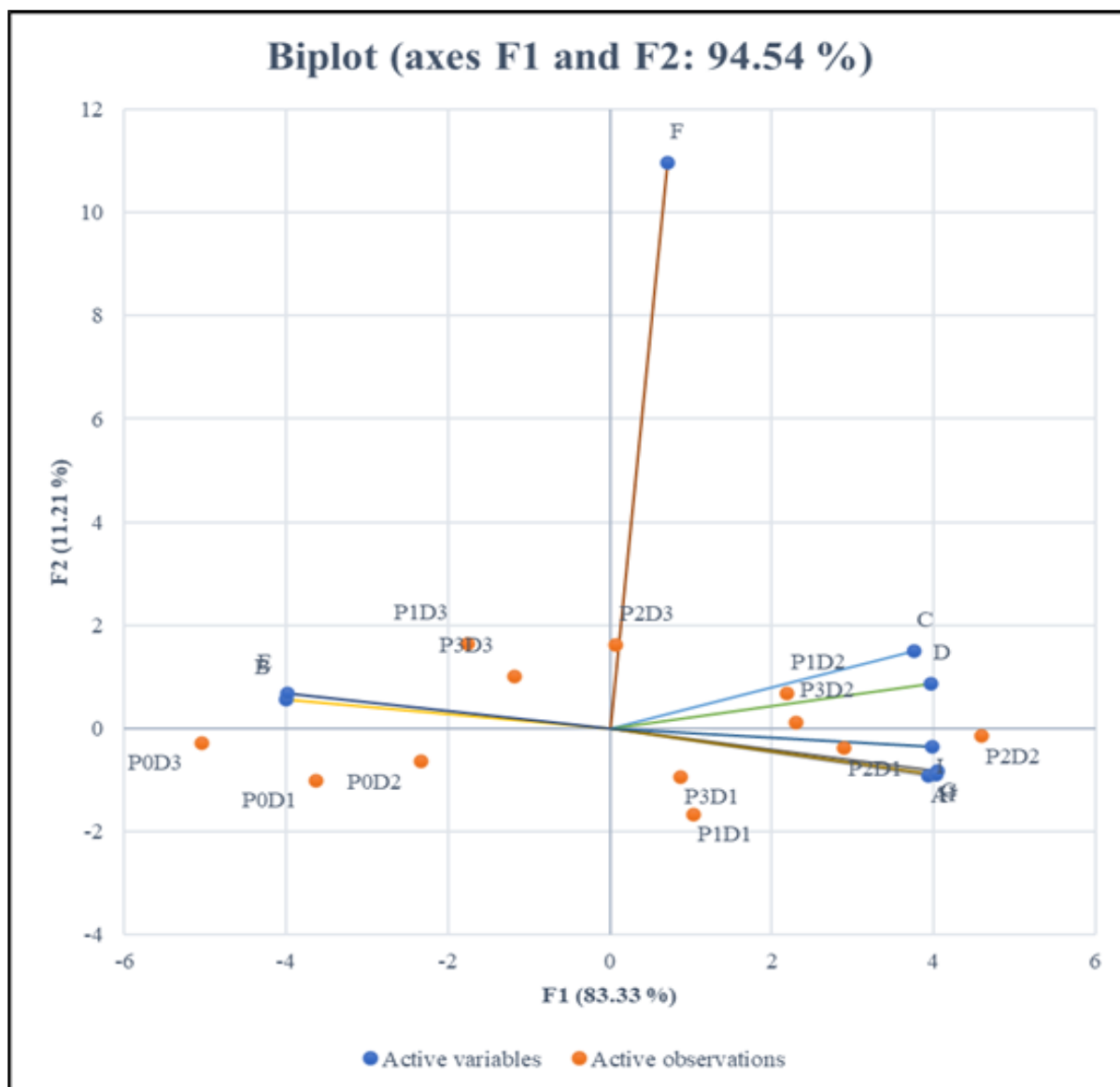


Fig. 3. Principal component analysis (PCA) biplot of quality traits (red vectors) and treatment combinations (blue dots) of dried rose flowers based on the first two principal components ($F_1 = 83.33\%$, $F_2 = 11.21\%$). Variables: A = Diameter of dry flower, B = Weight of dry flower, C = Reduction in total weight, D = Moisture loss (%), E = Shrinkage ratio, F = Brittleness, G = Texture, H = Colour, I = Shape. Treatments pretreated with glycerol and dried for 2.5 to 3.5 min (P_2D_1 , P_2D_2) cluster with high-quality traits (G–I), while P_0D_3 and P_1D_3 align with traits associated with poor quality, such as brittleness (F) and shrinkage (E).

tool for assessing postharvest quality traits in dried rose flowers. Principal Component Analysis summarised most of the variation in quality traits within the first two components, which together explained 94.54 % of the total variance. PC1 represented major structural and sensory attributes, including texture, colour, shape and moisture loss, whereas PC2 was mainly associated with brittleness. These findings suggest that PC1 functions as a comprehensive degradation index, reflecting the overall decline in quality due to moisture loss and structural collapse. In contrast, PC2 isolates brittleness as an independent trait, likely influenced by prolonged or intense drying. This separation is consistent with previous research on dried *Gardenia jasminoides* flowers, where PCA differentiated fresh from dried samples based on key quality parameters, with PC1 and PC2 explaining a cumulative 84 % of the variance (15).

Similarly, studies on dried petals from *Centaurea cyanus* demonstrated that different drying protocols (e.g., shade drying, hot-air convective drying, freeze-drying) led to distinct clustering in PCA plots, based on biochemical and physicochemical changes such as antioxidant content and moisture loss (16). The strong negative

correlation observed between dry weight and moisture loss ($r = -0.952$) and between shrinkage ratio and shape ($r = -0.95$) further supports the interconnected nature of physical and visual quality degradation in dried flowers. The superior performance of glycerol-treated flowers (P_2D_1 and P_2D_2) can be attributed to their humectant and plasticising properties, which help retain moisture and maintain the flexibility of petal tissues. Glycerol also stabilises the cell wall matrix, reducing structural damage and shrinkage during drying. In contrast, prolonged microwave drying (4.5 min) leads to rapid moisture loss and overheating, resulting in cell wall collapse and increased brittleness. Thus, optimised drying duration combined with glycerol pretreatment is essential for preserving quality. Multivariate analysis enabled the simultaneous evaluation of multiple quality traits and identified treatment combinations that maintained structural integrity and sensory quality in dried rose flowers.

Conclusion

This study evaluated the combined influence of chemical pretreatments and microwave drying durations on the quality traits of

dried rose flowers using multivariate statistical analysis, particularly PCA, are highly effective in assessing and streamlining complex postharvest quality traits in dried roses. Among all treatments, glycerol–water pretreatment combined with moderate microwave drying durations of 2.5–3.5 min consistently produced superior quality, preserving texture, colour, shape and structural integrity, whereas untreated controls under prolonged drying showed the greatest deterioration, marked by shrinkage, brittleness and moisture loss. These results validate that moisture regulation, structural stability and aesthetic appeal are interdependent and can be significantly improved through appropriate pretreatment and drying strategies, thereby providing practical insights for extending shelf-life and marketability of dried rose products. Future studies may focus on validating these findings across different rose cultivars and exploring biochemical attributes such as pigment stability and antioxidant retention to complement physical and sensory quality.

Acknowledgements

The authors acknowledge the support provided by Mahatma Gandhi Udyaniki Evam Vaniki Vishwavidyalaya, Durg, Chhattisgarh, India and the College of Horticulture and Research Station (CHRS), Sankra, for the research programme

Authors' contributions

DS conceptualized the study, conducted the experiments, analyzed the data and prepared the original draft of the manuscript. BS assisted with experimental work, data collection and manuscript revision. AD contributed to statistical analysis and interpretation of results. TLS supported laboratory work, microwave drying and quality evaluation of dried flowers. JKS supervised the research, provided critical inputs and approved the final manuscript. MP assisted in experimental execution and data recording. VT contributed to data analysis and methodology optimization. BR provided technical guidance and reviewed the manuscript. AK assisted in result interpretation and manuscript editing. All authors read and approved the final version of the manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None.

Declaration of generative AI and AI-assisted technologies in the writing process: The authors used generative AI and AI-assisted technologies (Chat GPT) during the preparation of this manuscript for language refinement and clarity improvement. The content was reviewed, verified and edited by the authors, who take full responsibility for the accuracy, originality and integrity of the work.

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Additional information

Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

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