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Standardization of Flower-decoction Levels for Quality and Storage Stability of Natural Gulal from Marigold (*Tagetes Erecta L.*) and Rose (*Rosa Spp.*)

Suhrrita Chakrabartty Das[1*], Sushmita Rana[1] and Karabi Biswas[2]

[1]*Department of Post Harvest Technology, Faculty of Horticulture, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, Nadia 741 252, West Bengal, India*
[2]*Department of Botany, University of Kalyani, Kalyani, Nadia 741 235, West Bengal, India*

* Corresponding author. E-mail: suhritakvk@gmail.com

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ABSTRACT

The study aimed to standardize an aqueous flower-decoction and arrowroot formulation for natural gulal from marigold and rose and to determine how formulation and season of preparation affected product quality during ambient storage. Experiments were conducted during 2022–23 and 2023–24 at Bidhan Chandra Krishi Viswavidyalaya, West Bengal, using six decoction levels (40, 50, 60, 70, 80 and 90 ml per 50 g arrowroot) in a completely randomized design with four replications in summer, rainy and winter seasons. Moisture level, colour retention, pH and nine-point hedonic sensory acceptability were recorded at 0, 30, 60, 90 and 120 days. The 90 ml treatment maintained the highest absolute colour-retention score in freshly prepared marigold and rose gulal (4.06 and 4.83, respectively) and the highest sensory acceptability (8.32 and 8.43); at 120 days it still recorded sensory scores of 6.67 and 6.60. Cooler-season preparation generally improved colour and sensory performance, while moisture and pH declined progressively during storage. Treatment × season effects were significant for the principal quality attributes, and correlation analysis showed strong continuity among successive storage observations. Small-scale production generated gross benefit:cost ratios of 2.26 for marigold and 1.80 for rose. The 90 ml decoction with 50 g arrowroot, particularly under winter preparation, was the most dependable formulation for floral value addition and decentralized gulal production.

INTRODUCTION

Floriculture generates substantial quantities of flowers that are downgraded, left unsold after market peaks, or discarded after ceremonial use. Converting colour-rich floral biomass into stable value-added products can reduce postharvest loss while creating short-cycle income opportunities around major festivals. Gulal, the coloured powder traditionally used during Holi, is a relevant outlet because plant-derived pigments can provide attractive shades without depending on synthetic industrial dyes. Concerns have been raised regarding particulate matter, heavy metals and irritant colourants in some commercial Holi powders (Rawat, 2008; Das *et al.*, 2015; Bossmann *et al.*, 2016; Gupta *et al.*, 2019). Plant-based formulations using inexpensive carrier materials therefore have both environmental and livelihood relevance, although product quality and safety should be evaluated separately.

Marigold (*Tagetes erecta* L.) and rose (*Rosa* spp.) are suitable candidates for natural gulal production because they are widely cultivated and their petals contain visually distinct pigment systems. Earlier studies have demonstrated the feasibility of extracting natural colourants from ornamental plant materials (Kashyap *et al.*, 2017; Gopika *et al.*, 2018; Elshemy *et al.*, 2019). More specifically, Basumatary *et al.* (2021) prepared eco-friendly Holi powders using natural plant dyes with tapioca and rice flour as low-cost filler bases and demonstrated their immediate sensory acceptability relative to commercial Holi powder. Their study established the feasibility of starch-based natural Holi formulations, but focused primarily on filler-base comparison and consumer preference of freshly prepared

products rather than systematic optimization of the quantity of floral extract incorporated into a fixed carrier or its quality changes during storage.

Arrowroot (*Maranta arundinacea* L.) starch offers a neutral carrier with useful binding, swelling and powder-forming properties (Ai & Jane, 2018). However, the volume of aqueous floral decoction incorporated into a fixed quantity of carrier can influence initial moisture, pigment intensity, powder texture and subsequent storage stability. Moreover, temperature and relative humidity associated with different seasons of preparation may modify drying and storage behaviour. To our knowledge, information remains limited on the systematic optimization of graded flower-decoction levels in an arrowroot-based gulal formulation, particularly with respect to multi-season performance, temporal changes in moisture, colour, pH and sensory acceptability during ambient storage, and small-scale production economics.

On this basis, it was hypothesized that increasing the volume of flower decoction incorporated into a fixed quantity of arrowroot would enhance pigment intensity and sensory quality up to an optimum level, whereas excessive liquid loading could compromise drying and subsequent storage stability; these responses were also expected to vary with season of preparation. Preliminary formulation trials indicated that decoction levels below 40 ml per 50 g arrowroot produced inadequate colour development, whereas levels above 90 ml resulted in an excessively wet mixture and prolonged drying. Accordingly, the range of 40–90 ml decoction per 50 g arrowroot, at 10-ml intervals, was selected for systematic evaluation.

The present two-year investigation therefore aimed to (i) standardize the flower-decoction level for marigold- and rose-based gulal using a constant arrowroot carrier; (ii) quantify the effects of formulation and season of preparation on physicochemical and sensory quality during 120 days of ambient storage; (iii) determine whether quality measurements made at earlier storage intervals were associated with, and could provide an indication of, subsequent storage performance; and (iv) assess the small-scale economic feasibility of the best-performing formulation.

MATERIALS AND METHODS

The investigation was conducted during 2022–23 and 2023–24 in the Laboratory of the Department of Post Harvest Technology of Horticultural Crops, Faculty of Horticulture, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, Nadia, West Bengal, India. The work was repeated in the three principal local seasons, viz. summer, rainy and winter. Fresh, turgid and fully opened marigold and rose flowers with uniform colour and without visible damage were collected from the Horticulture Instructional Farm, Jaguli, and the Horticulture Research Station, Mondouri. Standardized fresh flowers were used in the experiment so that treatment effects could be separated from deterioration of the raw material; the developed protocol is intended for later adaptation to hygienically collected surplus or downgraded flowers.

Aqueous flower decoction was prepared separately for marigold and rose. One kilogram of cleaned petals was heated with 650 ml water at 50–70°C for 30 min, with intermittent pressing of the softened petals to facilitate pigment release. The extract was then filtered through cloth or sieve. No alum, mordant or other pH-adjusting agent was added to the decoctions used in the experiment. The experimental range was finalized on the basis of preliminary formulation trials. Decoction volumes below 40 ml per 50 g arrowroot produced insufficient colour development, whereas volumes above 90 ml generated an excessively wet mixture that required prolonged drying and was less suitable for subsequent grinding and powder preparation. Therefore, six graded decoction levels from 40 to 90 ml at 10-ml intervals were selected for the main experiment. Six treatments were constituted with a fixed 50 g arrowroot base: T1, 40 ml decoction; T2, 50 ml; T3, 60 ml; T4, 70 ml; T5, 80 ml; and T6, 90 ml decoction. The decoction and arrowroot were mixed thoroughly, spread in a thin layer for shade or ambient drying, broken and ground after drying, sieved to obtain a uniform powder and packed in 12 × 10 cm polypropylene bags. The principal preparation steps and representative products are shown in Fig. 1.

The six treatments were evaluated separately for marigold and rose in a completely randomized design with four replications during each season and year. Colour was documented using the Royal Horticultural Society (RHS) Colour Chart, while visual colour retention during storage was rated on an ordinal five-point scale, where 5 represented the brightest/least faded

Figure 1. Preparation and demonstration of floral gulal: (a) sorting/handling marigold flowers, (b) aqueous pigment extraction and mixing, (c) blending with arrowroot carrier, (d) group-scale preparation/drying, (e) marigold material during drying, (f) rose material during drying, (g) finished marigold gulal and (h) finished rose gulal

material and 1 the most faded. Because this variable was ordinal, colour-retention scores were analysed using non-parametric procedures rather than parametric ANOVA. Treatment differences at individual storage intervals were assessed using the Kruskal–Wallis test, and repeated observations over storage were evaluated using an appropriate Friedman procedure. Colour-retention data are therefore presented as medians with interquartile ranges.

Overall sensory acceptability was evaluated by a 10-member semi-trained panel comprising faculty members, research scholars, students and/or staff familiar with horticultural and postharvest quality evaluation. Before formal assessment, the panellists were oriented to the attributes to be evaluated and to the use of the nine-point hedonic scale (1 = dislike extremely; 9 = like extremely) following Peryam and Pilgrim (1957). Overall acceptability integrated visual colour and powder texture. Samples were presented under coded identities so that panellists were unaware of the corresponding treatment number. The same 10 panellists participated throughout the two experimental years and across the summer, rainy and winter evaluations. Each panellist assessed the samples independently and recorded scores without group discussion.

For each of the four experimental replications, all 10 panellists evaluated the respective sample, and the mean of the 10 individual ratings was used as the sensory observation for that experimental replicate. Thus, the panellists functioned as assessors and were not treated as independent experimental replications; the experimental unit for statistical analysis was the replicate-level panel mean (n = 4 per treatment × season combination). Sensory evaluations were conducted at 0, 30, 60, 90 and 120 days of ambient storage. Treatment, season and treatment × season effects were analysed separately at each storage interval. Storage time was not incorporated as a repeated-measures factor in the original ANOVA; relationships among measurements at successive storage intervals were examined separately using temporal correlation analysis.

Moisture level was recorded monthly using a portable digital two-probe moisture meter (Model MD7822; S/N S342255). The readings were independently cross-checked with a sensor-based digital moisture meter (Model MMD7NP; S/N 20220417956) to verify measurement consistency. Stabilized readings were expressed as percentage moisture. Because no matrix-specific gravimetric calibration against an oven-drying reference method was performed, the values are interpreted as comparative instrumental moisture measurements rather than reference-method absolute moisture contents.

The experiment was conducted independently during 2022–23 (Year 1) and 2023–24 (Year 2), with four replications in each year. Year-wise replicated means were retained separately before pooling, as documented in the original experimental dataset. Before presentation of pooled means, the consistency of responses between years was examined by including year as an additional factor and assessing the year effect and year × treatment interaction. Treatment responses showed no meaningful year-dependent reversal, and the year × treatment interaction was non-significant ($p > 0.05$); consequently, data from the two years were pooled for the subsequent treatment × season analysis and presentation.

Statistical analyses were performed using the web-based OPSTAT statistical package developed by O.P. Sheoran and colleagues, Department of Mathematics and Statistics, Chaudhary Charan Singh Haryana Agricultural University, Hisar, India (Sheoran *et al.*, 1998; OPSTAT online application). The browser-based application used for the analysis did not display a numerical software-version identifier. Data were analysed according to a completely randomized design, with treatment, season and treatment × season effects evaluated at each storage interval. Where significant, means were separated using Duncan's Multiple Range Test (DMRT) at $p = 0.05$.

Economic feasibility was assessed for a representative 10 kg batch using the input prices and operational costs recorded during the experimental period (2022–24) at the small-scale experimental unit. For marigold gulal, the recorded production cost was ₹1,060 per 10 kg, comprising flowers, arrowroot and other ingredients, and operational costs including fuel, polypropylene packaging, essential oil and labour. For rose gulal, the corresponding production cost was ₹1,780 per 10 kg, including flowers, arrowroot and operational expenses for fuel, polypropylene packaging and labour. Sale values were based on the prices at which the experimental products were sold during the study: ₹60 per 250-g packet for marigold and ₹80 per 250-g packet for rose, equivalent to ₹2,400 and ₹3,200 per 10 kg, respectively. The gross benefit:cost ratio was calculated as gross sale value/total production cost, and the net profit:cost ratio as net return/total production cost. These estimates represent the prevailing prices and small-scale production conditions of the experimental period and should not be interpreted as current or universally applicable market prices.

RESULTS

Moisture content

Decoction level, season and their interaction affected the moisture response of both marigold and rose gulal (Table 1). In marigold, the pooled treatment mean immediately after preparation increased from 11.63–11.67% in the lower-decoction treatments to 12.08% in T6. The treatment × season comparison showed the

Table 1

Treatment	Summer	Rainy	Winter	Mean
Marigold - freshly prepared (0 d)				
T1	11.56^{bcd}	11.75^{abcd}	11.69^{abcd}	11.67
T2	11.44^{d}	11.56^{bcd}	11.88^{abcd}	11.63
T3	11.75^{abcd}	11.63^{bcd}	11.63^{bcd}	11.67
T4	11.81^{abcd}	11.94^{abcd}	11.81^{abcd}	11.85
T5	12.06^{abc}	12.13^{ab}	11.50^{cd}	11.90
T6	11.88^{abcd}	12.13^{ab}	12.25^{a}	12.08
Mean	11.75	11.85	11.79	
SEm± (Season, Treatment, S×T): 0.073, 0.104, 0.18; CD (p=0.05): 0.205, 0.292, 0.505				
Marigold - 120 d storage				
T1	10.94^{ab}	10.50^{bcde}	10.25^{def}	10.56
T2	10.50^{bcde}	10.38^{bcdef}	10.31^{cdef}	10.40
T3	10.56^{bcde}	10.44^{bcdef}	10.56^{bcde}	10.52
T4	10.69^{abcd}	10.06^{ef}	9.94^{f}	10.23
T5	10.69^{abcd}	10.94^{ab}	10.88^{abc}	10.83
T6	11.19^{a}	10.63^{bcd}	10.81^{abcd}	10.88
Mean	10.76	10.49	10.46	
SEm± (Season, Treatment, S×T): 0.069, 0.097, 0.169; CD (p=0.05): 0.194, 0.272, 0.474				
Rose - freshly prepared (0 d)				
T1	11.63^{cde}	10.63^{hi}	10.13^{ij}	10.79
T2	11.19^{efg}	10.25^{hij}	10.00^{j}	10.48
T3	11.75^{bcd}	10.75^{fgh}	10.63^{hi}	11.04
T4	11.94^{abc}	11.25^{def}	10.25^{hij}	11.15
T5	12.25^{ab}	11.50^{cde}	10.50^{hij}	11.42
T6	12.31^{a}	10.69^{gh}	10.56^{hi}	11.19
Mean	11.84	10.84	10.34	
SEm± (Season, Treatment, S×T): 0.069, 0.098, 0.17; CD (p=0.05): 0.194, 0.275, 0.477				
Rose - 120 d storage				
T1	10.00^{bc}	8.69^{de}	8.44^{ef}	9.04
T2	9.75^{c}	8.63^{def}	8.25^{f}	8.88
T3	9.94^{bc}	8.56^{def}	8.44^{ef}	8.98
T4	10.13^{ab}	8.63^{def}	8.50^{def}	9.08
T5	10.38^{a}	8.75^{de}	8.38^{ef}	9.17
T6	10.25^{ab}	8.75^{de}	8.88^{d}	9.29
Mean	10.07	8.67	8.48	
SEm± (Season, Treatment, S×T): 0.048, 0.068, 0.118; CD (p=0.05): 0.135, 0.191, 0.331				

maximum fresh value in T6 during winter (12.25%), whereas several lower-dose combinations were statistically at par. By 120 days, the marigold treatment means ranged from 10.23% in T4 to 10.88% in T6. Across seasons, the 120-day mean was 10.76% in summer, 10.49% in the rainy season and 10.46% in winter.

Table 1 Effect of flower-decoction treatment and season on moisture level (%) of marigold and rose gulal at preparation and after 120 days of ambient storage

Values are pooled means of two years. Means within a species × storage interval carrying a common superscript letter are not significantly different by Duncan's Multiple Range Test at p=0.05. S, season; T, treatment. T1-T6 = 40, 50, 60, 70, 80 and 90 ml flower decoction per 50 g arrowroot, respectively.

Rose gulal showed distinct seasonal differences. Fresh treatment means ranged from 10.48% in T2 to 11.42% in T5, while the corresponding seasonal means were 11.84% in summer, 10.84% in the rainy season and 10.34% in winter. At 120 days, the seasonal means were 10.07, 8.67 and 8.48%, respectively. T6 recorded a treatment mean of 9.29%, while T2 recorded 8.88%.

The temporal correlation analysis showed positive associations among successive moisture observations. In marigold, moisture readings at 90 and 120 days were strongly correlated (r = 0.84), while in rose, strong correlations were observed between 60 and 90 days (r = 0.84) and between 90 and 120 days (r = 0.93) (Fig. 2).

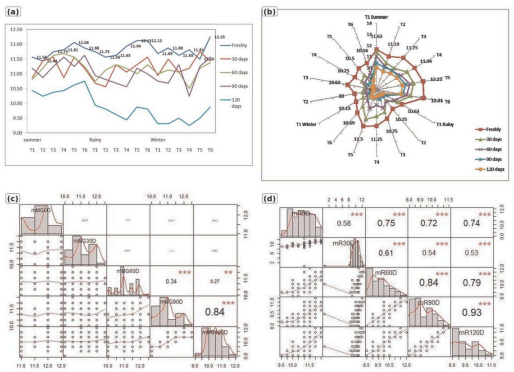

Figure 2. Moisture behaviour of gulal during storage: (a) marigold treatment-season profile, (b) rose treatment-season profile, (c) correlation matrix for marigold and (d) correlation matrix for rose. Correlation asterisks are reproduced from the original thesis analysis.

Table 2

Treatment	Summer	Rainy	Winter	Mean
Marigold - freshly prepared (0 d)				
T1	3.00^{e}	3.19^{de}	3.56^{bcde}	3.25
T2	3.38^{cde}	3.75^{bcd}	3.25^{de}	3.46
T3	3.13^{de}	3.31^{de}	3.70^{bcd}	3.38
T4	3.31^{de}	3.25^{de}	4.00^{abc}	3.52
T5	4.00^{abc}	3.75^{bcd}	3.75^{bcd}	3.83
T6	4.06^{ab}	3.75^{bcd}	4.38^{a}	4.06
Mean	3.48	3.50	3.77	
SEm± (Season, Treatment, S×T): 0.078, 0.110, 0.190; CD (p=0.05): 0.219, 0.309, 0.533				
Marigold - 120 d storage				
T1	2.25^{d}	2.19^{d}	2.19^{d}	2.25
T2	2.25^{d}	2.19^{d}	2.19^{d}	2.29
T3	2.19^{d}	2.13^{d}	2.13^{d}	2.27
T4	2.13^{d}	2.38^{cd}	2.38^{cd}	2.21
T5	2.25^{d}	2.69^{bc}	2.69^{bc}	2.38
T6	2.38^{cd}	3.13^{a}	2.75^{b}	2.75
Mean	2.24	2.45	2.45	
SEm± (Season, Treatment, S×T): 0.046, 0.065, 0.112; CD (p=0.05): 0.129, 0.182, 0.314				
Rose - freshly prepared (0 d)				
T1	3.56^{efg}	3.31^{g}	3.81^{de}	3.56
T2	3.69^{def}	3.81^{de}	4.13^{bc}	3.88
T3	3.56^{efg}	3.50^{fg}	4.13^{bc}	3.73
T4	3.88^{cd}	3.88^{cd}	4.63^{a}	4.13
T5	4.25^{b}	4.75^{b}	4.88^{a}	4.63
T6	4.81^{a}	4.88^{a}	4.81^{a}	4.83
Mean	3.96	4.02	4.40	
SEm± (Season, Treatment, S×T): 0.038, 0.054, 0.094; CD (p=0.05): 0.107, 0.151, 0.264				
Rose - 120 d storage				
T1	2.94^{abcd}	2.75^{bcde}	2.75^{bcde}	2.81
T2	2.69^{cde}	2.81^{abcde}	2.63^{de}	2.71
T3	2.56^{e}	2.69^{cde}	2.88^{abcde}	2.71
T4	2.75^{bcde}	2.81^{abcde}	3.00^{abc}	2.85
T5	2.81^{abcde}	2.88^{abcde}	3.00^{abc}	2.90
T6	3.06^{ab}	3.00^{abc}	3.13^{a}	3.06
Mean	2.80	2.82	2.90	
SEm± (Season, Treatment, S×T): 0.042, 0.06, 0.104; CD (p=0.05): 0.118, 0.168, 0.292				

Colour retention

Higher-decoction treatments recorded higher colour-retention scores in both gulal types (Table 2). Fresh marigold gulal prepared with T6 had a pooled colour-retention score of 4.06 and reached 4.38 in the winter treatment × season combination. T5 recorded a fresh pooled score of 3.83, whereas T1–T4 recorded treatment means ranging from 3.25 to 3.52.

Table 2 Effect of flower-decoction treatment and season on colour-retention score (1–5; higher score = less fading) of marigold and rose gulal

Values are pooled means of two years. Means within a species × storage interval carrying a common superscript letter are not significantly different by Duncan's Multiple Range Test at p=0.05. S, season; T, treatment. T1-T6 = 40, 50, 60, 70, 80 and 90 ml flower decoction per 50 g arrowroot, respectively.

A similar pattern was observed in rose gulal. T6 recorded a fresh pooled score of 4.83 and T5 recorded 4.63, compared with 3.56 in T1. The Royal Horticultural Society colour classes also differed among treatments, ranging from pale RHS 4D/15D in the lower marigold treatments to RHS 22A in the higher treatments, and from lighter rose shades in T1–T3 to RHS 64D–63B in T4–T6.

Colour-retention scores decreased during storage in all treatments. At 120 days, T6 maintained the highest pooled colour score, with values of 2.75 in marigold and 3.06 in rose. The treatment × season comparison at 120 days showed a score of 3.13 for marigold T6 prepared in the rainy season and 3.13 for rose T6 prepared in winter. The 120-day marigold seasonal mean was lowest in summer (2.24).

Correlations among successive colour-retention assessments were positive in both flower types. Marigold colour scores at 90 and 120 days were correlated at r = 0.69, while rose scores at 30 and 60 days were correlated at r = 0.83 (Fig. 3).

pH changes

Marigold and rose gulal differed in initial pH, and both showed a general decline during storage (Table 3). Fresh marigold treatment means ranged from 4.23 in T1 to 4.72 in T5 and 4.69 in T6. At 120 days, the treatment means ranged from 3.24 to 3.45. The highest individual fresh value was 4.91 in winter-prepared T5.

Table 3

Treatment	Summer	Rainy	Winter	Mean
Marigold - freshly prepared (0 d)				
T1	4.28^{def}	4.08^{f}	4.33^{def}	4.23
T2	4.49^{bcde}	4.08^{f}	4.16^{ef}	4.24
T3	4.41^{bcdef}	4.56^{abcd}	4.70^{abc}	4.56
T4	4.56^{abcd}	4.28^{def}	4.47^{bcde}	4.43
T5	4.63^{abcd}	4.61^{abcd}	4.91^{a}	4.72
T6	4.72^{abc}	4.78^{ab}	4.56^{abcd}	4.69
Mean	4.51	4.40	4.52	
SEm± (Season, Treatment, S×T): 0.050, 0.070, 0.112; CD (p=0.05): 0.140, 0.196, 0.314				
Marigold - 120 d storage				
T1	3.14^{c}	3.37^{bc}	3.23^{bc}	3.24
T2	3.39^{bc}	3.27^{bc}	3.24^{bc}	3.30
T3	3.49^{bc}	3.47^{bc}	3.40^{bc}	3.45
T4	3.54^{b}	3.16^{bc}	3.36^{bc}	3.35
T5	3.39^{bc}	3.13^{c}	3.33^{bc}	3.28
T6	3.22^{bc}	3.88^{a}	3.14^{c}	3.41
Mean	3.36	3.38	3.28	
SEm± (Season, Treatment, S×T): 0.047, 0.066, 0.114; CD (p=0.05): 0.132, 0.185, 0.320				
Rose - freshly prepared (0 d)				
T1	7.20^{a}	7.16^{a}	7.03^{a}	7.13
T2	7.09^{a}	7.00^{a}	7.02^{a}	7.04
T3	5.81^{cd}	5.69^{cde}	6.14^{bc}	5.88
T4	5.08^{g}	5.23^{efg}	6.29^{b}	5.54
T5	5.39^{defg}	5.44^{defg}	5.20^{fg}	5.34
T6	5.59^{def}	5.82^{cd}	6.52^{b}	5.98
Mean	6.03	6.06	6.37	
SEm± (Season, Treatment, S×T): 0.063, 0.089, 0.154; CD (p=0.05): 0.177, 0.250, 0.432				
Rose - 120 d storage				
T1	6.35^{a}	5.53^{b}	4.43^{efgh}	5.43
T2	6.28^{a}	5.35^{bc}	5.01^{cd}	5.55
T3	4.70^{de}	4.38^{efgh}	4.30^{efghi}	4.46
T4	4.40^{efgh}	4.17^{ghi}	4.33^{efghi}	4.30
T5	4.66^{def}	3.96^{hi}	3.87^{i}	4.16
T6	5.11^{bcd}	4.55^{efg}	4.19^{fghi}	4.62
Mean	5.25	4.65	4.35	
SEm± (Season, Treatment, S×T): 0.060, 0.086, 0.148; CD (p=0.05): 0.168, 0.241, 0.415				

Table 3 Effect of flower-decoction treatment and season on pH of marigold and rose gulal at preparation and after 120 days of ambient storage

Values are pooled means of two years. Means within a species × storage interval carrying a common superscript letter are not significantly different by Duncan's Multiple Range Test at p=0.05. S, season; T, treatment.

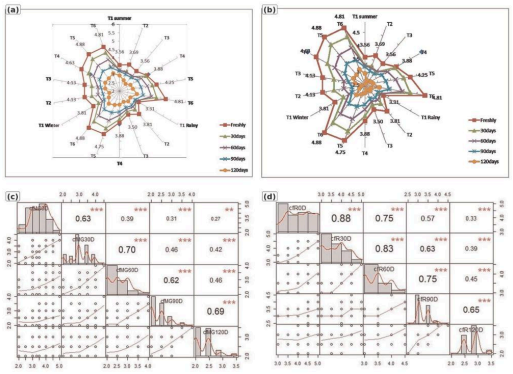

Figure 3. Colour-retention response during storage: (a) marigold treatment-season profile, (b) rose treatment-season profile, (c) correlation matrix for marigold and (d) correlation matrix for rose. Higher scores indicate less fading; correlation asterisks are reproduced from the original thesis analysis.

T1-T6 = 40, 50, 60, 70, 80 and 90 ml flower decoction per 50 g arrowroot, respectively.

Rose gulal showed a wider range of initial pH values. T1 and T2 recorded fresh pooled means of 7.13 and 7.04, respectively, while T3–T6 ranged from 5.34 to 5.98. At 120 days, T1 and T2 recorded pooled means of 5.43 and 5.55, respectively, whereas T5 declined to 4.16 and T6 to 4.62.

Positive correlations were observed among pH measurements recorded at successive storage intervals. In marigold, the correlation between 90- and 120-day values was r = 0.81, while in rose the correlations between adjacent late-storage intervals reached r = 0.92–0.93 (Fig. 4).

Sensory acceptability

Overall sensory acceptability differed among decoction treatments and seasons (Table 4). Fresh marigold gulal recorded pooled scores ranging from 6.22 in T1 to 8.32 in T6, while the winter T6 combination reached 8.76. T4 and T5 also recorded comparatively high scores during winter.

Table 4 Effect of flower-decoction treatment and season on overall sensory acceptability (nine-point hedonic scale) of marigold and rose gulal

Table 4

Treatment	Summer	Rainy	Winter	Mean
Marigold - freshly prepared (0 d)				
T1	6.54^{efg}	5.71^{h}	6.43^{efg}	6.22
T2	6.49^{efg}	5.58^{h}	6.88^{e}	6.32
T3	6.23^{g}	5.39^{h}	7.92^{c}	6.51
T4	6.72^{ef}	6.38^{fg}	8.66^{ab}	7.25
T5	7.34^{d}	6.53^{efg}	8.64^{ab}	7.50
T6	8.30^{bc}	7.91^{c}	8.76^{a}	8.32
Mean	6.94	6.25	7.88	
SEm± (Season, Treatment, S×T): 0.059, 0.083, 0.144; CD (p=0.05): 0.166, 0.233, 0.404				
Marigold - 120 d storage				
T1	4.18^{fgh}	4.84^{def}	4.19^{fgh}	4.40
T2	4.04^{gh}	4.96^{de}	3.95^{gh}	4.31
T3	3.75^{h}	5.05^{de}	4.52^{efg}	4.44
T4	4.58^{efg}	5.48^{cd}	5.87^{c}	5.31
T5	4.94^{de}	5.08^{de}	6.19^{bc}	5.40
T6	6.84^{ab}	7.03^{a}	6.14^{c}	6.67
Mean	4.72	5.41	5.14	
SEm± (Season, Treatment, S×T): 0.096, 0.136, 0.235; CD (p=0.05): 0.269, 0.381, 0.659				
Rose - freshly prepared (0 d)				
T1	5.52^{f}	5.67^{f}	6.64^{cde}	5.95
T2	5.67^{f}	6.19^{def}	6.65^{cde}	6.17
T3	6.18^{def}	6.00^{ef}	6.97^{bc}	6.38
T4	7.29^{bc}	7.00^{bc}	6.72^{bcd}	7.00
T5	7.08^{bc}	7.37^{b}	7.40^{b}	7.28
T6	8.46^{c}	8.49^{a}	8.33^{a}	8.43
Mean	6.70	6.79	7.12	
SEm± (Season, Treatment, S×T): 0.087, 0.123, 0.213; CD (p=0.05): 0.244, 0.345, 0.597				
Rose - 120 d storage				
T1	4.13^{gh}	4.06^{gh}	5.06^{de}	4.42
T2	3.96^{h}	4.92^{ef}	4.86^{ef}	4.58
T3	4.52^{fg}	4.95^{ef}	5.52^{cd}	5.00
T4	5.00^{ef}	5.29^{cde}	5.68^{c}	5.32
T5	4.83^{ef}	5.23^{cde}	6.20^{b}	5.42
T6	6.33^{ab}	6.69^{a}	6.77^{a}	6.60
Mean	4.79	5.19	5.68	
SEm± (Season, Treatment, S×T): 0.066, 0.094, 0.162; CD (p=0.05): 0.185, 0.264, 0.454				

Values are pooled means of two years; sensory panel comprised 10 semi-trained judges. Means within a species × storage interval carrying a common superscript letter are not significantly different by Duncan's Multiple Range Test at p=0.05. S, season; T, treatment. T1-T6 = 40, 50, 60, 70, 80 and 90 ml flower decoction per 50 g arrowroot, respectively.

Rose gulal showed a similar treatment response. Fresh pooled sensory scores ranged from 5.95 in T1 to 8.43 in T6, with the highest treatment × season score of 8.49 recorded in rainy-season T6.

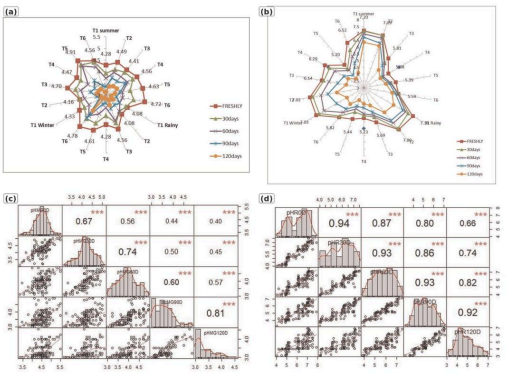

Figure 4. pH response during storage: (a) marigold treatment-season profile, (b) rose treatment-season profile, (c) correlation matrix for marigold and (d) correlation matrix for rose. Correlation asterisks are reproduced from the original thesis analysis

Sensory acceptability decreased during storage in all treatments. At 120 days, T6 retained the highest pooled sensory scores in both flower types, with 6.67 in marigold and 6.60 in rose. These values represented approximately 80.2% and 78.3% of their respective initial T6 scores. In marigold, T1–T3 recorded 120-day values ranging from 4.31 to 4.44, whereas T4 and T5 recorded 5.31 and 5.40. In rose, the 120-day scores ranged from 4.42–5.00 in T1–T3, 5.32–5.42 in T4–T5 and 6.60 in T6. Winter preparation recorded the highest 120-day seasonal mean for rose gulal (5.68), whereas marigold showed a stronger treatment × season response, with rainy-season T6 reaching 7.03.

Temporal correlations were also observed for sensory acceptability. Fresh and 120-day sensory scores were correlated at r = 0.53 in marigold and r = 0.76 in rose, while several correlations between adjacent storage intervals exceeded r = 0.80 (Fig. 5).

Texture, colour class and analytical storage period

Qualitative texture differed among decoction treatments (Table 5). T1–T3 were recorded as fine powders,

Table 5

Treatment	Formulation	Marigold colour	Rose colour	Texture
T1	40 ml decoction + 50 g arrowroot	RHS 4D	RHS 68C	Fine
T2	50 ml decoction + 50 g arrowroot	RHS 15D	RHS 68C	Fine
T3	60 ml decoction + 50 g arrowroot	RHS 15D	RHS 70C	Fine
T4	70 ml decoction + 50 g arrowroot	RHS 21B	RHS 64D	Smooth
T5	80 ml decoction + 50 g arrowroot	RHS 22A	RHS 64D	Smooth
T6	90 ml decoction + 50 g arrowroot	RHS 22A	RHS 63B	Smooth

Table 6

Item	Marigold gulal (₹)	Rose gulal (₹)
Flower petals (20 kg)	200	1000
Arrowroot and other ingredients (10 kg)	450	450
Operational cost (fuel, packaging, essential oil/labour as recorded)	410	330
Total production cost	1060	1780
Sale value (40 packets × 250 g)	2400	3200
Net return	1340	1340
Gross benefit:cost ratio	2.26	1.80
Net profit:cost ratio	1.26	0.75

whereas T4–T6 were described as smooth. T5 and T6 also corresponded to the stronger Royal Horticultural Society colour classes recorded for both marigold and rose gulal. The complete physicochemical and sensory evaluations in the present study were conducted up to 120 days of ambient storage; therefore, interpretation of storage performance was restricted to this experimentally evaluated period.

Table 5 Formulation, Royal Horticultural Society colour class and qualitative texture of marigold and rose gulal

RHS, Royal Horticultural Society colour chart. Longer storage up to 24 months was recorded descriptively in the thesis; inferential evaluation in this paper is restricted to 120 days.

Economic feasibility

For a representative 10 kg marigold gulal batch of the selected formulation, total production cost was ₹1,060 and the estimated sale value was ₹2,400, resulting in a net return of ₹1,340, a gross benefit:cost ratio of 2.26 and a net profit:cost ratio of 1.26 (Table 6).

Table 6 Cost-benefit analysis of the selected T6 formulation at small scale (10 kg gulal powder)

Costs and sale values are those recorded in the original small-scale experiment and are not adjusted for subsequent price changes.

For rose gulal, the total production cost was ₹1,780 and the estimated sale value was ₹3,200, giving a net return of ₹1,340, a gross benefit:cost ratio of 1.80 and a net profit:cost ratio of 0.75.

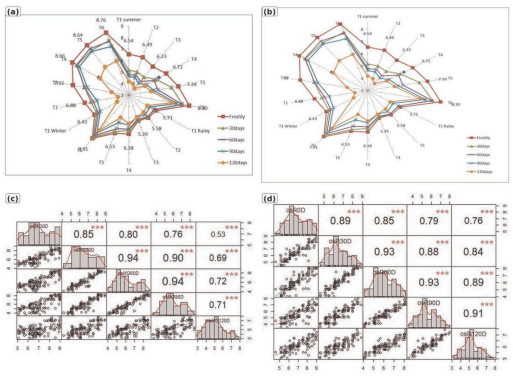

Figure 5. Overall sensory acceptability during storage: (a) marigold treatment-season profile, (b) rose treatment-season profile, (c) correlation matrix for marigold and (d) correlation matrix for rose. Correlation asterisks are reproduced from the original thesis analysis.

DISCUSSION

Effect of decoction level and season on moisture behaviour

The relatively higher initial moisture values at the greater decoction levels were expected because increasing quantities of aqueous flower extract were incorporated into a constant 50 g arrowroot base. Subsequent reduction in moisture during storage indicated continued drying and equilibration of the powder with the surrounding environment.

Arrowroot starch has the capacity to swell and bind water during mixing and subsequently forms a dry powder matrix as moisture is removed. The observed decrease in moisture during storage is therefore compatible with the functional behaviour of starch as a carrier (Ai & Jane, 2018). Seasonal differences, particularly those observed in rose gulal, further indicate that the drying environment influenced the moisture status of the final product.

The strong positive associations among successive storage observations suggest that moisture changes

generally followed a consistent temporal pattern rather than fluctuating irregularly.

Effect of decoction level on colour and colour retention

The higher colour scores and stronger RHS colour classes obtained with T5 and T6 indicate that increasing the amount of pigment-bearing flower decoction relative to a fixed quantity of arrowroot enhanced the visual colour intensity of the prepared gulal. This effect was evident in both marigold and rose.

The reduction in colour-retention scores during storage was consistent with gradual degradation of natural floral pigments. Marigold colour is associated largely with carotenoids and xanthophylls, whereas rose colour is associated predominantly with anthocyanin pigments. Such pigments may undergo changes during storage due to oxidation, temperature, light exposure and the physicochemical environment of the dried matrix. Plant-derived pigments are known to differ considerably in stability depending on extraction conditions, carrier system and storage environment.

The higher initial pigment load in T5 and T6 probably contributed to their maintenance of greater absolute colour scores during storage, although proportional fading was not necessarily lowest in every treatment. The positive correlations among successive observations further indicate that formulations displaying better colour performance during earlier storage generally tended to retain comparatively better colour at later intervals.

Changes in pH during storage

The progressive decline in pH during storage was a notable physicochemical change in both gulal types. Marigold gulal, which was already moderately acidic immediately after preparation, reached pooled treatment means of approximately pH 3.24–3.45 after 120 days, whereas the corresponding terminal values of rose gulal remained generally higher. Importantly, no alum, mordant or other pH-adjusting agent was added to the flower decoctions used in this experiment. Therefore, the observed acidification cannot be attributed to hydrolysis of potassium aluminium sulphate or to an alum-mediated mordant effect.

Because pH was measured after reconstitution of the stored powder rather than directly in the dry matrix, the values represent the acid–base characteristics of water-extractable constituents of the formulation. The gradual decrease may reflect storage-related chemical changes in floral pigments, phenolic compounds and other soluble constituents, including oxidation or hydrolytic reactions that alter the balance of acidic and basic species, together with changes associated with moisture equilibration during storage. However, titratable acidity, individual organic acids and degradation products were not quantified in the present study; consequently, the chemical pathway responsible for the pH decline cannot be established from these measurements alone.

The relatively low terminal pH of marigold gulal nevertheless has practical relevance because the product is intended for external use and may accidentally contact the eyes or other sensitive surfaces during Holi application. Normal human skin surface is itself mildly acidic and is commonly reported within approximately pH 4–6, although it varies with anatomical site and other factors. Thus, a reconstituted pH of approximately 3.2–3.5 is below the usual physiological skin-surface range and warrants specific compatibility testing before commercial use. However, pH alone should not be interpreted as evidence that the formulation is irritant or unsafe. Regulatory testing frameworks regard much more extreme pH values (approximately ≤2 or ≥11.5, together with acid/alkali reserve) as indicators of potential corrosivity, and biological response also depends on buffering capacity, concentration, exposure duration and formulation characteristics.

Accordingly, the present pH results should be regarded as physicochemical storage-quality data rather than a demonstration of dermal safety. Before commercialization, the formulation should be subjected to validated skin-irritation/compatibility testing and, because accidental facial and ocular exposure is possible during use, appropriate eye or mucosal safety assessment. Such testing is particularly important for the more acidic marigold formulations after prolonged storage.

Sensory acceptability and practical product quality

Sensory acceptability declined progressively during storage in both gulal types, although T6 remained the highest-rated formulation at 120 days. The initial T6 scores of 8.32 for marigold and 8.43 for rose declined to 6.67 and 6.60, respectively, corresponding to retention of approximately 80.2% and 78.3% of their initial scores. Percentage retention alone, however, may overstate practical acceptability when the initial score is high. The absolute endpoint scores are therefore more informative. On the nine-point hedonic scale used in the study, a score of 6 represents “like slightly,” 5 represents “neither like nor dislike,” and 4 represents “dislike slightly.” For practical interpretation of the present results, a mean score of ≥6 was considered a minimum positive-acceptability benchmark, although this was applied post hoc and should not be interpreted as an independently validated commercial acceptance threshold.

On this basis, T6 remained within the positively acceptable range after 120 days for both marigold (6.67) and rose (6.60), but its endpoint acceptability was moderate rather than high. In contrast, the lower-decoction marigold treatments, which ended at approximately 4.31–4.44, were between the neutral and slightly dis-

liked region of the scale and would not satisfy the ≥6 practical benchmark. Similarly, the lower rose treatments, with endpoint scores of approximately 4.42–5.00, were at or below the neutral level. T4 and T5 also declined below 6 at 120 days. Thus, the practical advantage of T6 is better described as maintenance of positive sensory acceptability through 120 days rather than simply as high percentage retention.

Accordingly, the 120-day period should be regarded as the demonstrated analytical storage period under the experimental conditions, not as an independently validated commercial shelf life. Commercial shelf-life specification would additionally require confirmation of microbiological quality, physicochemical stability, packaging performance and product safety.

Texture, colour class and storage interpretation

The progressive reduction in colour-retention score during storage is consistent with the known storage sensitivity of the major pigment classes associated with marigold and rose. Marigold colour is largely associated with xanthophyll carotenoids, particularly lutein, although individual pigments were not quantified in the present study. Carotenoids contain an extended conjugated double-bond system that is susceptible to oxidation and cis–trans isomerisation during storage. In dried powder systems, lutein loss increases with exposure to oxygen, light and elevated temperature; Li *et al.* (2014), for example, reported greater all-trans-lutein degradation and formation of cis-isomers in air- and light-exposed freeze-dried powder than under vacuum and dark storage. Similar effects of temperature, oxygen and packaging/light exposure on lutein degradation have been demonstrated in spray-dried vegetable powder (Syamila *et al.*, 2019). These mechanisms are therefore more directly relevant to the gradual fading observed in marigold gulal than the previously cited betacyanin-based food system.

In rose gulal, anthocyanins are likely to make an important contribution to the red–pink colour. Anthocyanin colour and stability are strongly influenced by temperature, light, oxygen, moisture and pH. Studies specifically involving rose powder have shown progressive anthocyanin loss with storage time and increasing temperature (Barani *et al.*, 2020; Barani *et al.*, 2023), while solid-state anthocyanins have also been shown to undergo substantial photochemical degradation and increased degradation under elevated temperature and humidity (Otto *et al.*, 2024).

The observed decline in the pH of rose gulal should not, however, be interpreted simply as the cause of anthocyanin fading. In aqueous systems, anthocyanin molecular forms are strongly pH-dependent: more acidic conditions favour the coloured flavylium form, whereas within approximately pH 3–6 increasing proportions of hydrated, weakly coloured or colourless forms may occur. Thus, the movement of the reconstituted rose-gulal pH towards the acidic range would not by itself explain the observed decrease in colour-retention score. Rather, pigment degradation through light-, oxygen-, temperature- and moisture-associated reactions, together with changes in the physicochemical environment of the dried starch matrix, is a more plausible explanation. Moreover, because pH in the present study was measured after reconstitution, these values should be interpreted as an indicator of the acid–base characteristics of the product and not as a direct measurement of proton activity within the dry powder matrix.

No alum, mordant or other pH-adjusting agent was added to either marigold or rose decoction in the experiment; consequently, alum-mediated complexation or effects on carotenoid/anthocyanin stability did not contribute to the present results. The powders were packed in polypropylene bags. Polypropylene provides a useful physical and moisture barrier but is not completely impermeable to gases; oxygen transmission through PP films depends on film structure, thickness and storage temperature, and permeability generally increases with temperature. Therefore, some oxygen transfer through the package during prolonged ambient storage is possible and could contribute to oxidative pigment deterioration. Because the thickness, oxygen-transmission rate and controlled light-transmission characteristics of the particular PP bags were not measured in this experiment, the contribution of packaging permeability should be considered mechanistically plausible rather than experimentally demonstrated.

Future studies should quantify individual carotenoids and anthocyanins during storage and compare packaging materials of known oxygen- and light-barrier properties to distinguish pigment degradation from purely visual colour changes.

Economic and practical implications

The economic analysis indicated favourable small-scale returns for both flower types, with marigold showing a higher gross benefit:cost ratio than rose. The difference was primarily associated with the higher raw-flower cost of rose rather than with differences in the basic processing sequence.

The preparation method requires relatively simple operations involving aqueous extraction, mixing, drying, grinding, sieving and packaging and does not depend on solvent extraction or highly specialized processing equipment. This supports its potential suitability for household-, cooperative- or small-enterprise-level production. Earlier studies have similarly proposed natural dyes combined with low-cost filler materials as

accessible alternatives for preparation of Holi colours (Das *et al*., 2015; Basumatary *et al*., 2021).

However, the economic estimates represent the experimental production scale. Actual commercial profitability would depend on local flower prices, labour charges, packaging costs, availability of hygienically acceptable raw material, regulatory compliance and market acceptance.

Limitation and applicability to surplus floral material

An important limitation is that the present formulation was standardized using fresh, turgid and uniformly coloured flowers. This approach minimized raw-material deterioration as an additional source of experimental variation and allowed the effects of decoction level, season and storage to be evaluated more clearly. However, pigment yield, moisture behaviour, pH and sensory performance obtained from fresh flowers should not automatically be assumed to be identical when senescent or post-market floral material is used.

The present formulation should therefore be regarded as a standardized baseline. Its application to hygienically acceptable surplus or downgraded flowers requires separate validation, particularly with respect to pigment recovery, moisture behaviour, microbiological quality and storage stability.

Economic feasibility

The selected formulation was economically attractive at the small experimental scale (Table 6). For a 10 kg marigold gulal batch, total production cost was ₹1,060 and sale value ₹2,400, giving a net return of ₹1,340, gross benefit:cost ratio of 2.26 and net profit:cost ratio of 1.26. Rose gulal had a higher raw-flower cost: total cost was ₹1,780 against a sale value of ₹3,200, again yielding ₹1,340 net return but lower gross and net ratios of 1.80 and 0.75. The difference was therefore driven primarily by flower cost rather than by the basic processing sequence. At decentralized scale, the method requires simple heating, mixing, drying, grinding and packaging rather than solvent extraction or specialized equipment, which supports its suitability for seasonal enterprise development. Natural-dye and low-cost filler approaches have similarly been proposed as accessible alternatives for Holi colour production (Das *et al*., 2015; Basumatary *et al*., 2021). Actual commercial margins will nevertheless depend on local flower price, hygienic raw-material sourcing, packaging, labour, regulatory compliance and market acceptance.

CONCLUSION

The study identified 90 ml flower decoction mixed with 50 g arrowroot (T6) as the most consistently acceptable formulation for both marigold and rose gulal. T6 maintained comparatively higher colour-retention and sensory scores throughout the 120-day analytical storage period and was economically feasible at the experimental small scale. However, the influence of season was flower-specific rather than uniform. Although cooler-season preparation generally favoured initial quality, marigold T6 showed better colour retention after 120 days when prepared during the rainy season (score 3.13) than during winter (2.75), whereas rose T6 showed the highest 120-day colour-retention score during winter (3.13). Therefore, T6 is recommended as the common formulation, while the preferred preparation season should be considered separately for the two flower types rather than prescribing winter universally.The protocol provides a standardized baseline for value addition of fresh floricultural material using simple unit operations; its extension to surplus or downgraded flowers should be validated separately with respect to pigment recovery, physicochemical quality, microbiological status and storage stability.Commercial adoption should, however, include standardised moisture determination, microbiological quality assessment, contaminant screening and skin-safety validation before product claims are made.

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CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

ETHICAL COMPLIANCE

No ethical issues were identified in relation to the study.

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