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Sustainable nutrition from edible chrysanthemums: evaluating genotypes for nutritional, antioxidant, and consumer preference attributes

Hoora Bayanifar[1], Davood Hashemabadi[1*†] and Mohammad Sadegh Allahyari[2*†]

†Davood Hashemabadi and Mohammad Sadegh Allahyari contribute equally

*Correspondence:
Davood Hashemabadi
hashemabadi@iau.ac.ir
Mohammad Sadegh Allahyari
ms.allahyari@iau.ac.ir
[1]Department of Horticulture, Ra.C, Islamic Azad University, Rasht, Iran
[2]Department of Agricultural Management, Ra.C, Islamic Azad University, Rasht, Iran

Abstract

Despite growing demand for edible flowers as nutritious and sustainable food sources, limited data exist on the nutritional potential and consumer acceptance of *Chrysanthemum morifolium* genotypes. This study evaluated 20 modified chrysanthemum genotypes at the Mahallat Research Institute, Iran, to identify the best-performing genotypes. The research, conducted from November 2022 to October 2023, comprised two phases: experimental and survey-based. Data were collected on the nutritional value, biological properties, antioxidant capacity, and consumer preferences of the 20 genotypes. Using the multi-attribute decision-making (MADM) method, weights were assigned to these four indicators via the CRITIC method. The genotypes were then ranked using three MADM techniques: TOPSIS, ARAS, and WASPAS. The rankings derived from these methods were combined and analyzed using the mean rank method. In the experimental phase, genotype Code 110 demonstrated the highest nutritional and biological values, attributed to an elevated iron content of 2.77 mg/kg fresh weight and significant calcium levels. Conversely, Code 751 exhibited the highest antioxidant capacity, as assessed by the DPPH method. During the survey phase, Codes 674, 562, and 354 received the highest consumer preference scores, largely due to their appealing appearances and favorable nutritional profiles. Utilizing multi-attribute decision-making methods, Codes 110 and 603 were ranked first and second, respectively. These results underscore the potential of chrysanthemums as a sustainable source for nutrition and health; however, challenges such as limited consumer acceptance, post-harvest processing issues, market constraints, genotype diversity, and the necessity for appropriate packaging warrant further investigation.

Keywords Multi-attribute decision-making, Chrysanthemum, Edible flower, TOPSIS, ARAS, and WASPAS

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1 Introduction

Food is fundamental to human survival, and the growth of the global population throughout history has rendered sustainable food supply a critical challenge [10]. Currently, the rapidly increasing human population encounters food scarcity as a result of overpopulation, abrupt shifts in climate patterns, and constrained natural resources [15]. These challenges have compelled humanity to adopt more prudent resource utilization and develop innovative agricultural practices that diverge from traditional methods in order to meet the food demands of a rapidly expanding population [29]. In this context, edible flowers have gained prominence in contemporary diets due to their nutritional value, bioactive compounds (e.g., antioxidants, vitamins, and minerals), and aesthetic appeal in culinary applications [22]. Historical evidence suggests that our ancestors demonstrated the edibility of flowers through their long-standing incorporation into cuisine. However, following World War I, during which private gardens were destroyed, the consumption of edible flowers declined in industrialized societies and was gradually forgotten. Nonetheless, a growing awareness of plant-based, health-oriented, and sustainable nutrition in recent decades has revitalized demand for these nutritious and decorative food sources [15, 22]. Research indicates that edible flowers can significantly contribute to meeting human dietary needs and may even replace staple foods during shortages of seasonal or fresh produce [21]. Key resources include edible flowers, vegetables, fruit trees, and medicinal and ornamental plants [7].

Chrysanthemum (*Chrysanthemum morifolium L.*), belonging to the Asteraceae family, ranks among the top ten cut flowers globally. Beyond its ornamental value, chrysanthemum holds significant medicinal, nutritional, industrial, and environmental importance. In its native region of China, its use as a medicinal and edible plant has a history spanning over 3000 years [11]. Biologically active compounds such as vitamins, flavonoids, sesquiterpenes, triterpenes, and unsaturated fatty acids have been identified in chrysanthemum. Nearly all parts of the plant, including roots, stems, leaves, and petals, have medicinal applications [17, 27]. The petals, which are the edible part, are consumed fresh, dried, steamed, or cooked in various dishes [17, 28]. Given the global ornamental value of cut chrysanthemum flowers, extensive breeding efforts have been undertaken to develop numerous cultivars and genotypes with exceptional ornamental traits, particularly in Iran. New cultivars are typically designed to enhance visual and qualitative features such as flower color, size, shape, aroma, quality, and shelf life [31].With minimal requirements for water and soil resources and a high nutritional density, chrysanthemums hold significant potential to enhance sustainable diets and food security [30]. However, the lack of comprehensive studies on their dietary profiles (e.g., iron, calcium, and vitamins), bioactive compounds, and consumer acceptance of various genotypes—particularly in key production regions such as Iran—restricts their full utilization as a functional food [10]. This knowledge gap, especially regarding genotypic diversity and consumer preferences, limits the global development of this food source [15]. This study aims to evaluate and characterize the nutritional value, biological value, antioxidant capacity, and consumer preferences of 20 chrysanthemum genotypes produced in Mahallat County as edible flowers to identify superior types for supporting sustainable nutrition and public health.

2 Materials and methods

2.1 Study site

Mahallat County, located in Markazi Province, southwest of Tehran Province (Geographical Organization of the Armed Forces, 2000), is recognized as a major hub for flower and ornamental plant production in Iran. The region ranks first in nationwide cut flower production, cultivating 900 hectares and achieving an annual output of 217 million cut flower stems, which includes species such as chrysanthemum (*Chrysanthemum morifolium*), rose (*Rosa spp.*), gladiolus (*Gladiolus spp.*), and carnation (*Dianthus caryophyllus*). Additionally, it demonstrates exceptional performance in the production of seasonal and bedding flowers, including tulip (*Tulipa spp.*), orchid (*Orchidaceae*), violet (*Viola spp.*), and jasmine. The region also yields 12 million pots of indoor plants annually, comprising species such as pothos (*Epipremnum aureum*), ficus (*Ficus spp.*), and begonia (*Begonia spp.*). Furthermore, the county is a leader in seed production, generating 10 tons of various seed types.

Mahallat County possesses unique geographical and climatic features. Situated in the central region of Iran, with an altitude of 1750 m, it is surrounded by high mountains, features a southward slope, and benefits from sandy soil texture—all of which create ideal conditions for flower and plant cultivation [8]. This favorable climate has made the region particularly suited for plant production. The Mahallat Flower and Ornamental Plants Research Institute, which houses collections of chrysanthemum and rhizomatous iris, serves as a specialized facility for the cultivation and breeding of 1000 chrysanthemum genotypes. Of these, 850 types have been developed, and 50 new cultivars have been officially registered, alongside the institute's annual exhibitions.

2.2 Flower selection in the studied climate

The target floral specimens were selected from a cohort of 850 chrysanthemum genotypes developed at the Mahallat Flower and Ornamental Plants Research Institute. These genotypes were cultivated through methodologies including hybridization and mutation, specifically gamma irradiation, to enhance phenotypic traits such as color, petal morphology, height, flower diameter, and petal count. They are propagated as genetically uniform clones through vegetative propagation techniques, specifically cuttings.The selection process considered various characteristics, including color, petal shape, height, diameter, and the number of petals. Table 1 and Figure 1 provide detailed information on the characteristics of the genotypes used in this study. In late summer 2022, rooted cuttings of 20 selected genotypes were cultivated in a greenhouse under controlled conditions in Mahallat County. By late October 2022, the flowers were harvested at full bloom. They were then transported to the experimental site at Islamic Azad University of Rasht Campus using appropriate packaging that adhered to transportation protocols. Samples were stored at 4 °C in a refrigerator to maintain freshness during analysis.

2.3 Method

To assess the nutritional value and consumer preferences for chrysanthemums as an edible flower, an experiment was conducted in two distinct phases involving 20 chrysanthemum genotypes. In the first phase, the genotypes' traits were analyzed in a laboratory. In the second phase, consumer preferences for selecting chrysanthemums as an edible

Table 1 The characteristics of 20 chrysanthemum genotypes used in the research

Code	Grade	Petal status	Flower diameter	Height	Extensiveness	Flower density
Code 108	2	Lowly petalous	5.5	67	Medium	Medium
Code 110	Premium	Highly petalous	4.5	44	High	High
Code 134	2	Highly petalous	4.3	67	High	High
Code 138	2	Highly petalous	4.5	44	Medium	Medium
Code 325	1	Semi-highly petalous	5.2	69	High	High
Code 326	Premium	Extremely petalous	5.5	68	High	High
Code 354	2	Semi-highly petalous	6.2	59	High	High
Code 462	2	Lowly petalous	4.2	69	High	High
Code 540	2	Lowly petalous	6.9	54	Low	Low
Code 562	2	Lowly petalous	4.5	47	High	High
Code 563	2	Semi-highly petalous	5.4	48	High	High
Code 603	2	Lowly petalous	4.5	59	High	High
Code 674	2	Medium petalous	7.1	45	High	Medium
Code 684	2	Semi-highly petalous	6.9	59	High	High
Code 685	1	Lowly petalous	6.5	64	High	High
Code 714	2	Lowly petalous	5.2	68	High	Medium
Code 751	2	Semi-highly petalous	6.3	74	High	High
Code 801	2	Extremely petalous	5.6	63	Medium	Medium
Code 822	2	Extremely petalous	5.9	46	Medium	Medium
Code 851	2	Semi-highly petalous	5.3	69	Medium	Medium

flower were examined through a survey using a structured questionnaire. Figure 2 illustrates the stages of the research process.

2.3.1 Trait evaluation

2.3.1.1 ***Antioxidant capacity*** The antioxidant capacity of the chrysanthemum samples was determined following the method by Brand-Williams et al. [4], based on the DPPH free radical inhibition property. A total of 1 g of fresh petals was extracted with 10 mL of pure methanol and left at room temperature for 2 h. The extract was then filtered using filter paper.

Subsequently, 50 µL of the filtered extract was mixed with 950 µL of 2,2-diphenyl-1-picrylhydrazyl (DPPH) solution and kept in the dark at room temperature for 15 min. The absorbance of the mixture was measured at 515 nm using a UV-303PD APEL spectrophotometer. The antioxidant capacity was expressed as the percentage of inhibition (DPPHsc%) and calculated using the following formula:

$$\%\mathrm{DPPHsc} = (\mathrm{Acont} - \mathrm{Asamp}) \times 100/\mathrm{Acont}$$

in which %DPPHsc is the inhibition percentage, Acont is the absorbance of the control sample and DPPH, and Asamp is the absorbance of the DPPH.

2.3.1.2 ***Nutritional value*** To evaluate the nutritional value of the edible chrysanthemum flowers, the content of vitamin C, vitamin A, protein, iron, and calcium was measured in the 20 genotypes. The overall nutritional value was then calculated using the formula provided in the Vegetable Cultivation Booklet by Dr. Kashi (University of Tehran):

$$Nutrition\ value = \frac{mg\ Vit\ C \Big/ 100\ g}{10} + mg\ Vit\ A \Big/ 100\ g + 5\,(\%prot) + 5\left(mg\ Fe \Big/ 100\ g\right) + \frac{mg\ Ca \Big/ 100\ g}{5}$$



Fig. 1 Chrysanthemum genotypes used in the research

2.3.1.3 ***Biological value*** To determine the biological value of edible chrysanthemum flowers, the contents of vitamin C, vitamin A, fiber, iron, and calcium were measured in the 20 genotypes. The biological value was subsequently calculated using the following formula:

$$Bilogical\ value = \frac{mg\ Vit\ C \Big/ 100\ g}{2} + mg\ Vit\ A \Big/ 100\ g + raw\ fibers\ (g) + \frac{mg\ Ca \Big/ 100g}{100} + \frac{mg\ Fe \Big/ 100\ g}{2}$$

2.3.1.4 ***Trait evaluation*** The measurement of the nutritional and biological values required the determination of the following traits.

(1) Vitamins A and C

Vitamin A was measured by saponifying the sample with alcoholic potash, followed by extracting retinol using a mixture of petroleum ether and diethyl ether in a centrifuge. The extract was evaporated to dryness with nitrogen gas, and the residue was dissolved in methanol before being analyzed using an HPLC device [32].

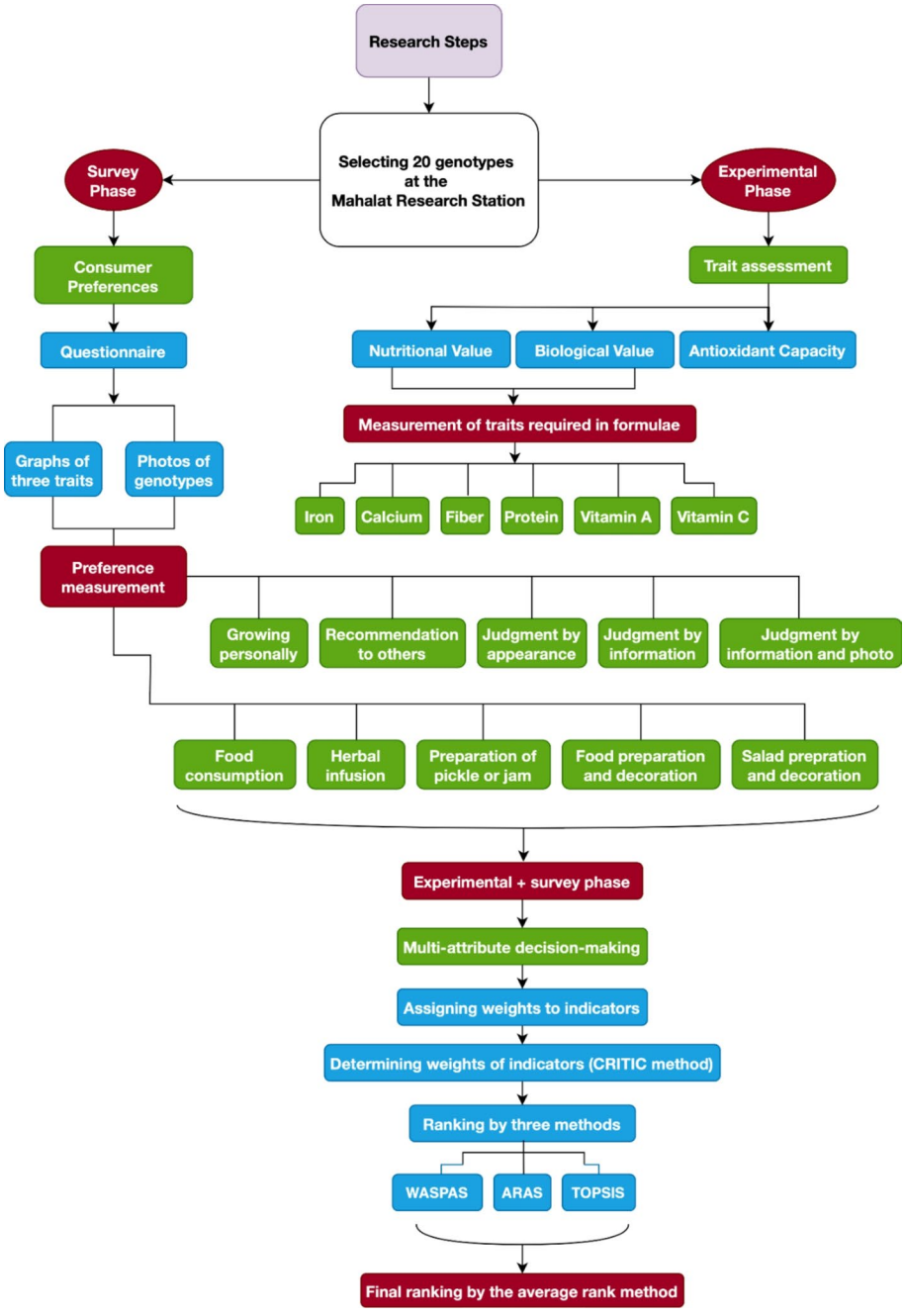


Fig. 2 Research steps

Vitamin C was measured using the titration method with 2,6-dichlorophenol indophenol. For this, 2 g of fresh petals were ground with liquid nitrogen, and 15 mL of 3% metaphosphoric acid was added and mixed thoroughly. The mixture was filtered and diluted to 10 mL with metaphosphoric acid. The titration was performed by adding 2,6-dichlorophenol indophenol until a pale pink color appeared. Vitamin C content, expressed as mg per 100 g of fresh weight (FW), was calculated using the formula provided by Mazumdar and Majumdar [18]:

$$\mathrm{C} = (e \times d \times b)/(c \times a) \times 100$$

in which a is the sample weight, b is the volume of metaphosphoric acid used for extraction, c is the volume of solution removed for titration, e is the volume of dye solution used for each sample, and d is the color factor. The color factor (d) was obtained from the following formula:

$$d = \frac{0.5}{\text{Amount of dye solution used to titrate the standard sample}}$$

(2) Petal protein

The Kjeldahl method was used to determine the petal protein of different chrysanthemum genotypes. The percentage of nitrogen in the samples was first calculated, and then the percentage of petal protein was estimated using the following formula:

$$\text{Protein } (\%) = \text{ N} \times 6.25$$

(3) Minerals (Fe and Ca)

To measure minerals in chrysanthemum petals, a 1-g extract of petal ash was prepared using the method of Rengel and Romheld [24]. The concentrations of calcium and iron in the petals were then determined using an atomic absorption spectrometer.

(4) Crude fiber

The percentage of crude fiber was calculated using the method described by Aryapak and Ziarati [2] with the following formula:

$$Crude\ fiber\ (\%) = \frac{Initial\ sample\ weight}{Crude\ fiber\ weight} \times\ 100$$

2.3.2 Questionnaire

To prepare a comprehensive questionnaire, extensive research and consultations with professors and experts were conducted to design questions to investigate consumer preferences. So, photographs of 20 chrysanthemum genotypes were included along with graphs related to nutritional value, biological value, and antioxidant capacity. Then, 10 statements were developed to assess the degree of willingness for consumption (buying for food consumption, growing for food consumption, and recommending to others for consumption), the method of consumption (food preparation and decoration, salad preparation and decoration, and preparation of pickles, jam, or herbal infusion), and the reason for selection (based on the image, the graph, or both). Responses were recorded as yes or no for each chrysanthemum genotype.

2.4 Multi-attribute decision-making (MADM) methods

Decision-makers often consider multiple criteria simultaneously when choosing an option from various alternatives. These criteria can sometimes be consistent, but they may also be contradictory. The decision-making process involves selecting an alternative from these options, and the choice is considered informed when more than one criterion is used. While decision-making based on a single criterion is simple and one-dimensional, many real-world problems cannot be evaluated by just one alternative. Classical optimization models typically focus on a single measurement criterion and can be linear, nonlinear, or mixed. However, researchers increasingly employ multi-attribute

decision-making models for more complex problems. These models use several criteria instead of relying on a single optimality criterion [20]. This approach is particularly useful when a problem involves various quantitative and qualitative indicators. The goal is to consider all these indicators simultaneously and identify the alternative that maximizes the overall utility [9]. In this study, three methods—TOPSIS, ARAS, and WASPAS—were used to rank and select the best chrysanthemum genotypes.

2.5 TOPSIS method

The TOPSIS method was introduced by Hwang and Yoon in 1981 [12]. In this decision matrix, m alternatives are evaluated by n indicators. The selected alternative should have the smallest distance from the positive ideal solution and the largest distance from the negative ideal solution [25]. The steps of this method are as follows:

Step 1: Calculate the normalized decision matrix:

$$\mathrm{V} = \mathrm{W}_{\mathrm{mn}} \times \mathrm{N}$$

in which V represents the weighted dimensionless matrix, W_{nn} represents the diagonal matrix of weights, and N represents the dimensionless matrix.

Step 2: Calculate the positive ideal solution (S^+):

If the criterion has a positive aspect (profit), we use.

$$S^+ = \left(V_1^+, V_2^+, \ldots, V_N^+\right) = \{(max_m V_{mn} | n \in C_{ben}), (min_m V_{mn} | n \in C_{cost})\}$$

in which V_n^+ represents the values of the positive indicator.

The best values are the largest for positive indicators and the smallest for negative indicators.

Step 3: Calculate the negative ideal solution S^-:

If the criterion has a negative aspect (cost), we use.

$$S^- = \left(V_1^-, V_2^-, \ldots, V_N^-\right) == \{(min_m V_{mn} | n \in C_{ben}), (max_m V_{mn} | n \in C_{cost})\}$$

in which V_n^- represents the values of the negative indicator.

For positive indicators, the worst values are the smallest, while for negative indicators, the worst values are the largest.

Step 4: Calculate the Euclidean distance of each alternative from the positive ideal solution S^+ and the negative ideal solution S^-:

$$d^+ = \sqrt{\sum (V_{ij} - V_j^+)^2}$$

in which d^+ represents the distance of the *i*th alternative from the positive ideal.

$$d^- = \sqrt{\sum (V_{ij} - V_j^-)^2}$$

in which *d* represents the distance of the *i*th alternative from the negative ideal.

Step 5: Calculate the relative closeness of an alternative to the ideal solution (CL_i^*):

$$\mathrm{CL}i* = \frac{d^-}{d^- + d^+}$$

The ranking of alternatives is based on the CL_i^* value; the higher the value for each alternative, the better.

2.6 ARAS method

The ARAS method was introduced by Zavadskas et al. [33]. In this decision matrix method, m alternatives are evaluated by n indicators. The steps are as follows:

Step 1: Build the decision matrix:

$$X = \begin{bmatrix} x_{01} & x_{0j} & \dots & x_{0n} \\ x_{i1} & x_{ij} & \dots & x_{in} \\ \dots & \dots & \dots & \dots \\ x_{m1} & x_{mj} & \dots & x_{mn} \end{bmatrix}$$
$$i = 0,\ 1, \dots, m$$
$$j = 1, \dots, n$$

in which *n* represents the number of criteria, *m* represents the number of alternatives, and X_{ij} represents the performance of the *i*th alternative based on the *j*th criteria.

If the optimal value of criterion j is unknown, then.

$x_{0j} = \max_i ij$, if $\max_i x_{ij}$ is preferable.

$x_{0j} = \min_i x_{ij}^*$, if $\min_i x_{ij}^*$ is preferable.

Step 2: Calculate the normalization of the decision matrix ($\bar{X}_{ij}$):

$$\bar{X} = \begin{bmatrix} \bar{x}_{01} & \bar{x}_{0j} & \dots & \bar{x}_{0n} \\ \bar{x}_{i1} & \bar{x}_{ij} & \dots & \bar{x}_{in} \\ \dots & \dots & \dots & \dots \\ \bar{x}_{m} & \bar{x}_{nj} & \dots & \bar{x}_{mn} \end{bmatrix}$$
$$i = 0,\ 1, \dots, m$$
$$j = 1, \dots, n$$

Positive criteria are normalized as follows:

$$\bar{x}_{ij} = \frac{x_{ij}}{\sum_{i=0}^{m} x_{ij}}$$

in which $\bar{x}_{ij}$ is the positive normalized criterion.

Negative criteria are normalized using the following relations:

$$x_{ij} = \frac{1}{x_{ij}^*}$$

$$\bar{x}_{ij} = \frac{x_{ij}}{\sum_{i=0}^{m} x_{ij}}$$

$$\widehat{x}_{ij} = \bar{x}_{ij} w_j$$

$$i = 0, \dots, m$$

in which $\bar{x}_{ij}$ represents the negative normalized criterion.

Step 3: Calculate the weighted normal matrix ($\widehat{X}$.):

$$\sum_{j=1}^{n} w_j = 1$$

in which W_j represents the criterion weight.

$$\hat{X} = \begin{bmatrix} \hat{x}_{01} & \hat{x}_{0j} & \dots & \hat{x}_{0m} \\ \hat{x}_{i1} & \hat{x}_{ij} & \dots & \hat{x}_{in} \\ \dots & \dots & \dots & \dots \\ \hat{x}_{m1} & \hat{x}_{nj} & \dots & \hat{x}_{mn} \end{bmatrix}$$
$$\mathrm{i} = 0,\ 1, \dots, \mathrm{m}$$
$$\mathrm{j} = 1, \dots,\ \mathrm{n}$$

Step 4: Calculate the value of the optimality function:

$$S_i = \sum_{j=1}^{m} \hat{x}_{ij}$$
$$\mathrm{i} = 0, \dots, \mathrm{m}$$

The alternative with the largest S_i is the reference.

Step 5: Calculate the degree of desirability of each alternative:

$$K_i = \frac{S_i}{S_0}$$
$$\mathrm{i} = 0, \dots, \mathrm{m}$$

2.7 WASPAS method

The proposed steps for the WASPAS approach based on the study [25] are presented as follows:

Step 1. Determine the normalized decision matrix R= $(r_{mn})_{M\times N}$ in the following way:

r_{mn} = $\frac{x_{mn}}{max_n x_{mn}}$ if n ϵ C_{ben}.

r_{mn} = 1 – $\frac{x_{mn}}{max_n x_{mn}}$ if n ϵ C_{cost}.

Where C_{ben} is the set of benefit criteria, C_{cost} is the set of cost criteria. For benefit criterion the highest value of alternative evaluation is preferred whereas for cost criterion – contrary – the lowest value.

Step 2. Calculate the weighted normalized decision matrix V = $(v_{mn})_{M\times N}$ using the weights values (W_n , $n = 1, \dots, N$) as follows:

$$V_{mn} = W_n \,.\, r_{mn}$$

Step 3. Aggregate the total relative importance of mth alternative as follows:

$$Q_m = \sum_{n=1}^{N} v_{mn}$$

WASPAS method as an approach combining Weighted Sum and Weighted Product Models (WSM and WPM). Zavadskas et al., [33] suggested that accuracy of WASPAS method is more advantageous than using only WPM or WSM.

Step 4. Determine the weighted sum model (WSM): aggregate the total relative importance of nth alternative in the following form:

$$Q_n^{(1)} = \sum_{n=1}^{N} W_n \cdot r_{mn}$$

Where r_{mn} is calculate using the formula.

Step 5. Determine the weighted product model (WPM): aggregate the total relative importance of nth alternative as follows:

$$Q_n^{(2)} = \Pi_{n=1}^{N} \left(v_{mn}\right)^{W_n}$$

Step 6. Calculate the total importance of nth alternative in the following form [25, 33].

$Q_n = \lambda.\ Q_n^{(1)} + (1-\lambda).\ Q_n^{(2)}, \lambda \in [0,1]$,

Where.

$$\lambda = \frac{\sum_{n=1}^{M} Q_n^{(2)}}{\sum_{n=1}^{M} Q_n^{(1)} + \sum_{n=1}^{M} Q_n^{(2)}}$$

2.8 Weighting the measured indicators

To score the antioxidant capacity, the experts and professors of agricultural sciences were surveyed about nutritional value, biological value, and preference indicators. Based on their collective opinions and the calculations performed, weights were assigned to indicators (Table 2).

2.9 Assigning the weight of indicators by the CRITIC method

The CRITIC method is instrumental in the decision-making process for assigning weights to indicators [1]. As an objective weighting method, it relies on the correlation between indicators to determine their respective weights [34]. Originally proposed by Diakoulaki et al. [6], the method is rooted in the principles of intensity of contrast and the contrasting characteristics of the indicators. Simply put, an indicator with a higher standard deviation and a lower correlation with other indicators is assigned a greater weight. The weight is determined using the CRITIC method through the following steps [3]:

$$\mathrm{X} = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix}$$

Step 1: Form a decision matrix as shown in the following equation. In this matrix, n rows and m columns represent the number of indicators used for decision-making.

Step 2: Normalize the decision matrix in Eq. (1) for indicators that are useful in decision-making.

Step 3: Calculate the weights by considering the standard deviation of each indicator and its correlation with other indicators (Eqs. 2 and 3).

Table 2 The weights assigned based on the experts' opinions

Indicator	Weight assigned
Antioxidant capacity	0.338
Nutritional value	0.303
Biological value	0.220
Preferences	0.139

$r_{ij} = \frac{x_{ij} - x_j^{min}}{x_j^{max} - x_j^{min}}$ Eq. 1 (data normalization).

$C_j = \sigma_j \sum_{i=1}^{m} (1 - r_{ij})$ Eq. 2 (Initial weights of criteria).

$w_j = \frac{C_j}{\sum_{i=1}^{m} C_i}$ Eq. 3 (Normal weights of criteria).

3 Finally rank the indicators using the average of the ranks

Decision-makers often utilize multiple methods rather than relying on a single approach, which can lead to varying ranking outcomes in MADM methods. To ensure consistency, the average rank method is applied. This approach involves summing the ranks assigned to each factor by different methods and dividing the total by the number of methods used [19]. In this study, the mean rank method was employed to integrate the rankings generated by three methods: TOPSIS, ARAS, and WASPAS.

4 Results

4.1 Phase 1: the traits measured

Table 3 summarizes the analysis and comparison of the means for the 20 studied genotypes. Code 751 exhibited the highest antioxidant capacity (DPPH inhibition), while Code 326 had the lowest. Code 110 recorded the highest iron content (2.77 mg/kg FW), followed by Codes 603 (2.06 mg/kg FW) and 326 (2.03 mg/kg FW), with Code 685 showing the lowest (0.98 mg/kg FW). Code 326 had the highest calcium content (63.5 mg/kg FW), while Codes 684 and 138 had the lowest (38.96 and 39.26 mg/kg FW, respectively). Code 138 showed the highest crude fiber content (19.15%), and Code 751 had the highest protein content (1.25%). Code 603 recorded the highest vitamin C content (11.56 mg/100 g FW), and Code 674 had the highest vitamin A content (0.24 mg/kg FW). Code 326 ranked lowest in vitamin A (0.09 mg/kg FW) and vitamin

Table 3 The results of the evaluated traits

Genotype	Fe (mg/kg FW)	Ca (mg/kg FW)	Total fiber	Total protein	Vit. A (mg/kg FW)	Vit. C (mg/100 g FW)	Antioxidant capacity	Nutritional value	Biological value
110 Code	2.77	46.06	16.25	0.825	0.002	10.37	69.5	2311.562	206.195
Code 674	1.25	59.42	14.5	0.875	0.24	10.71	56.25	1842.846	165.775
562 Code	1.63	46.8	13.16	1.025	0.008	11.39	52.08	1758.064	147.955
751 Code	1.17	44.83	14.68	1.25	0.002	10.2	73.33	1489.07	123.31
563 Code	1.5	45.33	15.43	0.675	0.002	10.54	62.5	1661.229	141.23
134 Code	1.6	52.27	15.86	0.875	0.002	11.05	72.5	1851.08	153.855
540 Code	1.31	60.52	11.2	0.75	0.083	11.22	57.58	1878.572	151.13
603 Code	2.03	49.28	11.98	1.125	0.002	11.56	70.41	2007.581	168.74
Code 851	1.61	46.87	12	0.95	0.002	10.71	57.91	1748.421	144.925
325 Code	1.23	47.92	12.71	0.83	0.002	10.54	63.33	1578.804	127.6
685 Code	0.98	47.44	14.55	0.875	0.002	10.04	64.58	1444.379	116.21
462 Code	1.8	51.38	15.36	0.685	0.002	11.39	69.58	1932.364	162.635
822 Code	1.68	50.2	11.81	0.715	0.002	11.39	57.91	1848.914	151.905
326 Code	2.06	63.5	16.18	0.675	0.002	10.71	50.05	2304.646	188.235
138 Code	1.11	39.26	19.15	0.72	0.121	10.54	57.58	1356.954	131.28
801 Code	1.07	40.34	13.73	0.675	0.002	10.54	61.66	1346.429	113.04
684 Code	1.12	38.96	13.79	0.875	0.002	10.37	51.33	1344.812	114.135
108 Code	1.66	49.59	16.63	1.005	0.002	10.88	64.16	1828.113	154.86
354 Code	1.27	53.72	12.65	0.695	0.002	10.21	57.91	1714.096	135.175
714 Code	1.56	55.47	14.17	0.75	0.002	10.71	68.33	1894.421	153.195

C (6.5 mg/100 g FW). Overall, Code 110 excelled in combined nutritional and biological values, while Codes 684, 138, and 801 consistently ranked lowest (Table 3).

4.2 Consumer preferences

After reviewing the questionnaire results and participants' responses, the average preference scores for each genotype were calculated. Codes 562, 674, and 354 received the highest scores, while Code 326 received the lowest (Table 4).

4.3 Genotypes ranking

As previously mentioned, 20 chrysanthemum genotypes were selected based on four traits: antioxidant capacity, nutritional value, biological value, and consumer preferences. It should be noted that antioxidant capacity, nutritional value, and biological value were studied in the laboratory, while consumer preferences were assessed through a questionnaire and survey, the results of which are summarized in Table 5.

Furthermore, weights (W) were assigned to the criteria using the CRITIC method based on the opinions of subject matter experts. The weight of each trait was determined on a scale from 0 to 1. The final weights were 0.338 for antioxidant capacity, 0.303 for nutritional value, 0.220 for biological value, and 0.139 for consumer preference (Table 5).

After finalizing the weights of the indicators and the results of the study, the ranks of the cultivars obtained using TOPSIS, ARAS, and WASPAS (Table 6) were averaged and ranked to determine the final ranking and select the superior genotypes for each trait.

According to Table 6, based on the TOPSIS method, cultivar 110 with a weight of 0.921, cultivar 603 with a weight of 0.696, and cultivar 462 with a weight of 0.630 ranked first, second, and third, respectively. Based on the ARAS method, cultivar 110 with a weight of 0.982, cultivar 603 with a weight of 0.891, and cultivar 134 with a weight of 0.872 ranked first, second, and third, respectively. Similarly, based on the WASPAS method, cultivar 110 with a weight of 2.48, cultivar 603 with a weight of 2.39, and

Table 4 Consumer preferences

Genotype	Mean consumer preference score (0–7)
562	3.564
674	3.532
354	3.512
822	3.464
751	3.428
684	3.428
851	3.284
108	3.274
462	3.264
138	3.236
685	3.228
325	3.184
603	3.048
134	3.036
110	2.996
801	2.948
563	2.916
540	2.88
714	2.784
326	2.744

Table 5 The antioxidant capacity, nutritional value, biological value, and consumer preference

Sample	Antioxidant capacity	Nutritional value	Biological value	Preference
1	69.5	2311.562	206.195	3.532
2	56.25	1842.846	165.775	3.464
3	52.085	1758.064	147.955	3.184
4	73.33	1489.07	123.31	3.428
5	62.5	1661.229	141.23	3.228
6	72.5	1851.08	153.855	3.564
7	57.585	1878.572	151.13	3.284
8	70.415	2007.581	168.74	3.264
9	57.915	1748.421	144.925	2.784
10	63.335	1578.804	127.6	3.016
11	64.585	1444.379	116.21	3.236
12	69.58	1932.364	162.635	3.048
13	57.915	1848.914	151.905	3.512
14	50.055	2304.646	188.235	3.036
15	57.585	1356.954	131.28	2.916
16	61.665	1346.429	113.04	3.276
17	51.335	1344.812	114.135	2.744
18	64.165	1828.113	154.86	2.996
19	57.915	1714.096	135.175	2.88
20	68.33	1894.421	153.195	2.948
W	0.338	0.303	0.220	0.139

Table 6 Ranking of genotypes by the average method

Genotype	TOPSIS		ARAS		WASPAS		Mean	Final rank
	C	Rank	K	Rank	Qi	Rank		
110	0.921	1	0.982	1	2.48	1	1.0	1
674	0.477	8	0.811	8	2.30	8	8.0	8
562	0.343	14	0.751	14	2.24	14	14.0	14
751	0.417	11	0.785	11	2.28	11	11.0	11
563	0.383	12	0.776	12	2.27	12	12.0	12
134	0.600	5	0.872	3	2.37	3	3.7	3
540	0.456	9	0.798	10	2.29	10	9.7	10
603	0.696	2	0.891	2	2.39	2	2.0	2
851	0.369	13	0.757	13	2.25	13	13.0	13
325	0.323	16	0.745	15	2.24	15	15.3	15
685	0.290	17	0.726	17	2.22	17	17.0	17
462	0.630	3	0.863	4	2.36	4	3.7	4
822	0.454	10	0.804	9	2.30	9	9.3	9
326	0.602	4	0.859	5	2.34	5	4.7	5
138	0.186	19	0.691	19	2.17	19	19.0	19
801	0.231	18	0.698	18	2.18	18	18.0	18
684	0.028	20	0.636	20	2.11	20	20.0	20
108	0.508	7	0.814	7	2.31	7	7.0	7
354	0.327	15	0.744	16	2.23	16	15.7	16
714	0.570	6	0.837	6	2.34	6	6.0	6

cultivar 462 with a weight of 2.36 ranked first, second, and third, respectively. Cultivar 714 ranked lowest by all three methods.

Based on the results, the rankings differed slightly depending on the method used. The ARAS and WASPAS methods produced similar results, which were slightly different from those of the TOPSIS method. To achieve a single result, the mean rank was used.

Overall, the highest average ranks were associated with cultivars 684 (mean rank 20), 138 (mean rank 19), and 801 (mean rank 18), while the lowest mean ranks were associated with cultivars 110 (mean rank 1) and 603 (mean rank 2) (Table 6).

The values presented in the TOPSIS, ARAS and WASPAS methods are relative and calculated for comparing and ranking the genotypes.

5 Discussion and conclusion

This study aimed to identify superior chrysanthemum genotypes for use as edible flowers. It provides a comprehensive evaluation of 20 Chrysanthemum morifolium genotypes, highlighting their potential as functional foods to meet nutritional and health demands [13, 27]. Code 110, which ranked first in both nutritional and biological values, exhibits the highest iron content among the 20 genotypes. Its superior performance, characterized by high iron (2.77 mg/kg FW) and fiber (19%) content, positions it as a promising candidate for addressing micronutrient deficiencies, particularly iron, in regions with a high prevalence of anemia [16]. Code 751 demonstrated the highest antioxidant capacity, likely attributable to its elevated phenolic content, which supports its therapeutic potential in alignment with findings on the bioactive compounds of chrysanthemum [15, 17]. These properties enhance the value of chrysanthemum as a nutrient-rich addition to plant-based diets, offering both dietary and health benefits.

In the survey section, Codes 674, 562, and 354 received the highest scores. Consumer preferences favored genotypes with vibrant colors and culinary versatility, such as Codes 674 (bright yellow), 562 (magenta), and 354 (pink), which aligns with research emphasizing the significance of visual appeal in food selection [14, 26]. However, the low consumer preference for Code 110, despite its nutritional superiority, indicates a challenge in balancing nutritional benefits with marketability. This may stem from its less vibrant coloration (likely white or cream) or unfamiliar flavor profiles, as noted in studies on edible flowers [7]. Addressing this challenge necessitates strategies such as targeted marketing campaigns, recipe development to enhance palatability, or breeding programs to improve aesthetic traits [31]. For instance, integrating Code 110 into visually appealing dishes, such as salads or desserts, could increase its consumer acceptance.

The use of multi-attribute decision-making (MADM) methods (TOPSIS, ARAS, WASPAS) with CRITIC weighting provided a robust framework for ranking genotypes based on nutritional, biological, antioxidant, and consumer preference criteria. This approach, supported by Ghafari et al. [9], ensures a holistic evaluation compared to single-criterion methods, enabling reliable identification of top candidates like Codes 110 and 603. The consistency of rankings across methods validates the study's methodology, reinforcing its applicability to other edible plants.

Despite these strengths, the study has limitations. The evaluation was confined to 20 genotypes, which may not adequately represent the full diversity of *Chrysanthemum morifolium*. Additionally, consumer preferences were assessed exclusively in Iran, which may not reflect global market trends. The absence of data on post-harvest processing (e.g., drying or extraction) limits insights into potential industrial applications [5]. These limitations underscore the necessity for broader studies to generalize findings and explore commercial potential.

Furthermore, the combined results of the experimental and survey phases indicate that chrysanthemum is a suitable and valuable food source. This study affirms the potential

Table 7 Key challenges of top-performing chrysanthemum genotypes

Genotype	Challenges related to consumer preferences	Challenges related to measured parameters	Challenges related to ranking methods	Key challenges (suggested in review)
Code 110	Yellow and full-petaled, leading to high consumer acceptance (top ranks in survey), but competing with Codes 674, 562, 354.	High iron (2.77 mg/kg FW) and fiber (19%) content, but lower vitamin C (8.5 mg/100 g FW).	Ranked first in TOPSIS, ARAS, WASPAS due to high weights for nutritional (0.303) and biological (0.220) values.	Need for marketing to compete with more diversely colored genotypes; need for improved post-harvest processing (e.g., edible coatings) to maintain freshness.
Code 603	White with lilac tint and low petal density, leading to moderate consumer acceptance (mean rank in survey).	High vitamin C (11.56 mg/100 g FW) and iron content, but lower fiber (15%).	Ranked second due to balanced nutritional and biological values.	Limited acceptance due to pale color and low petal density; need for marketing to increase consumer awareness.
Code 751	White and low petal density, leading to lower consumer acceptance (lower rank in survey).	High antioxidant capacity (DPPH), but average iron and calcium content.	Moderate rank due to high antioxidant weight (0.338) but lower nutritional value.	Limited acceptance due to unattractive color and low petal density; limited genotypic diversity for balanced traits.

of *Chrysanthemum morifolium* as a sustainable and nutritious food source, aligning with the demand for sustainable diets in light of global food challenges such as population growth and climate change [30]. Codes 110 and 603, which exhibit high nutritional value (iron and fiber in Code 110; vitamin C and iron in Code 603), along with Code 751, known for its high antioxidant capacity, are promising candidates for plant-based diets and the enhancement of public health [16]. Code 674, notable for its high consumer acceptance due to its vibrant yellow color and elevated vitamin A content, demonstrates strong potential for culinary applications; however, its limited nutritional value necessitates improvement [22]. These findings suggest that chrysanthemums can contribute to sustainable diets, particularly in cost-effective production regions such as Iran [23]. Nevertheless, challenges such as limited consumer acceptance due to less appealing colors (e.g., Code 110), post-harvest processing issues, market constraints (arising from low consumer awareness), and limited genotypic diversity impede the development of this food source [15].

5.1 Key challenges of top-performing chrysanthemum genotypes

Table 7 summarizes the key challenges of top-performing Chrysanthemum morifolium genotypes for food applications, illustrating how color, consumer preferences, nutritional parameters, and ranking methods impact their acceptance and commercial applicability.

5.2 Future research directions

Future research should evaluate a broader range of Chrysanthemum morifolium genotypes to identify additional candidates possessing balanced nutritional and aesthetic traits, thereby enhancing genotypic diversity and expanding commercial applications. Investigating post-harvest processing techniques, such as edible coatings (e.g., chitosan- or alginate-based coatings) and advanced packaging systems (e.g., active or smart packaging with oxygen and moisture sensors), has the potential to improve shelf life and prevent the oxidation of bioactive compounds, such as phenolics [5, 15]. These methodologies could facilitate the production of value-added products, including dietary

supplements, herbal teas, and fortified foods. Assessing consumer preferences across diverse global markets, particularly in Europe and Asia, would yield insights into cross-cultural acceptance and inform targeted marketing strategies aimed at increasing consumer awareness. Breeding programs should prioritize genotypes that combine high nutritional value (e.g., iron and vitamin C) with vibrant colors (e.g., yellow or pink) to bridge the gap between nutritional benefits and consumer appeal [31]. Moreover, longitudinal studies examining the health impacts of chrysanthemum consumption, particularly its antioxidant effects on reducing oxidative stress and improving digestive health due to high fiber content, could substantiate its role as a functional food [16]. These investigations should include clinical trials to assess the long-term effects of consuming superior genotypes (e.g., Codes 110 and 751) on health markers such as hemoglobin levels or inflammatory biomarkers. The application of artificial intelligence, including machine learning models for predicting genotype quality based on chemical and sensory traits or optimizing processing techniques (e.g., optimal drying conditions), could accelerate the selection of superior genotypes and enhance production efficiency [15]. Furthermore, the development of novel technologies, such as biosensors for monitoring quality throughout the supply chain, could aid in preserving bioactive compounds and improving market acceptance. These strategies, coupled with the integration of chrysanthemums into sustainable food systems, could maximize their commercial potential and contribute to global food security.

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Data availability
Data are available from the authors upon reasonable request from the corresponding author.

Declarations

Ethics approval and consent to participate
Ethical approval was not provided for this study on human participants because this study was conducted in conformance with the Declaration of Helsinki involving humans and all its later amendments.

Consent for publication
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