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Physical-chemical characteristics and modeling of the dehydration curve for *Viola x wittrockiana* mass loss

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ABSTRACT. The edible flowers have in their constitution proteins, lipids, starch, vitamins, important minerals for a healthy diet, as well as bioactive compounds recognized for their potential effects on human health. Due to the high perishability of the flowers, their marketing represents a challenge, and drying is a method that contributes to the preservation of the product. Given the above, the present study aims verify which is the curve that best adjusts to the mass loss during the dehydration process through the proposition of Boltzmann nonlinear regression model in face of classical dehydration curve models, as well measure in frozen flowers centesimal composition of *Viola* × *wittrockiana* flowers. The flowers were dehydrated at 30°C in an air circulation oven up to constant weight. The centesimal composition of the dehydrated *Viola* × *wittrockiana* is 84.69% humidity, 8.76% carbohydrates, 2.51% proteins, 2.41% crude fiber, 1.23% ash, 0.40% lipids and 48.68 Kcal. With respect to phenolic compounds, the frozen and dehydrated flowers showed 423 and 301 mg gallic acid equivalents per gram and, about antioxidant activity, showed 90.67 to 94.93% inhibition of the DPPH radical (2,2-Diphenyl-1-picrylhydrazyl) and 44.00 and 49.00 mg of Trolox.100 g^{-1}. The Boltzmann model showed best fit the mass loss of *Viola* × *wittrockiana* and through this model the maximum mass loss occurs with 0.16 g, the maximum rate of mass loss of *Viola* × *wittrockiana* occurs in 46.7 min, whose mass loss is 0.66 g. The dehydration proved to be an efficient method to preserve the flowers because the bioactive compounds did not present significant losses after the application of this process.

Keywords: pansy; edible flower; antioxidant activity; phytochemicals; nonlinear regression.

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Introduction

According to the Brazilian Institute of Floriculture (IBRAFLOR), Brazil is among the 15 largest producers of flowers in the world, with revenues of R$ 9,57 billion with a growth rate of 10%, and this activity is important for agribusiness. Brazil has approximately eight thousand flowers producers, where together they produce more than 2,500 species with 17,500 different varieties of plants, besides being responsible for 209,000 jobs (IBRAFLOR, 2021).

Some species of flowers are used in human food for hundreds of years and among them the *Boragoofficinalis* L., *Calendulaofficinalis* L., *Perlagoniumhortorum* L., *Tropaeolummajus* L., *Viola* × *wittrockiana* Gans, *Dianthuschinensis* L., and many others. The consumption of flowers has increased considerably because they contain vitamins, minerals, flavonoids, anthocyanins and carotenoids (Fernande, Saraiva, Pereira, Casal, & Ramalhosa, 2019; Koike et al., 2015). Some of these compounds have therapeutic actions and can be classified as functional foods because they are related to the prevention of chronic degenerative diseases, such as cancer, diabetes, cardiovascular diseases and others (Koike, Araújo, Negrão, Almeida-Murandian, & Villavicencio, 2021).

To be consumed, flowers must be nontoxic, i.e., flowers that are sold on floricultural crops that use some type of pesticide cannot be consumed (Nascimento, Moraes, Hanke, Ávila, & Nunes, 2018). In addition to bringing beauty to the dishes, flowers provide differential flavor (Benvenuti, Bortolotti, & Maggini, 2016), can be used in preparations of sauces, salads, bakery products, jams, syrups, honey, vinegar, oil, teas, candied, frozen, added in cheese, and also in wines and flavored liqueurs (Koike, Barros, Antonio, Ferreira, & Villavicencio, 2019).

The *Viola* × *wittrockiana*, popularly known as pansy, is a hybrid ornamental plant belonging to the Violáceae family and is a winter flower. Its current varieties result from the crossing of *V. tricolor, V. lutea, and V. altaica*. It has large and flat flowers with about 5 to 13 cm in diameter, its colors range from yellow, blue, purple, white, pink and Bordeaux red (Gonçalves, Silva, & Carlos, 2019b). This has stood out in culinary preparations not only for its flavor and beauty but due to its antioxidant properties and high content of phenolic compounds (Koike et al., 2021).

The flowers have high post-harvest perishability, so it is important to apply conservation methods that increase shelf life, given that they have 1 to 2 days useful life (Fernandes, Saraiva, Pereira, Casal, & Ramalhosa, 2019b). One of the methods widely applied in food is dehydration because it is easy to apply when compared to other methods (Fernandes et al., 2019a). Dehydration is defined as the withdrawal of water by applying heat under controlled conditions of temperature, humidity, air flow and the dehydration process must be adequate for each product (Silva, Fischer, & Zambiazi, 2020). As benefits of dehydration, the following can be highlighted: it allows to stabilize the properties of aromatic compounds at room temperature for a longer time; prevents enzymatic and oxidative degradation; provides mass reduction and energy savings; and allows the product to be available for consumption at all times of the year (Fellows, 2018).

In this sense, it is feasible to obtain information about the behavior of the dehydration process of *Viola* × *wittrockiana*. Such data can be obtained through mathematical-statistical models that describe the behavior of mass loss in relation to drying time (Onwude, Hashim, Janius, Nawi, & Abdan, 2016). These models are based on Newton's Law for cooling, which applies to mass transfer and it is assumed that conditions are isothermal and that resistance to moisture transfer is restricted to the product surface only. In this way and in the context of flower drying, such models become essential to determine the ideal time for water loss in flowers, as well as predict mass loss after a certain time (Gasparin, Christ, & Coelho, 2017).

Given the above, the present study aims verify which is the drying kinetics model that best fit to the loss of mass during the dehydration process through the fitting of mathematical-statistical models, as well and measure in frozen flowers the centesimal composition, pH, titratable acidity (expressed in g of citric acid 100 g^{-1}), total soluble solids (°Brix) and in dehydrated frozen flowers the total phenolic content and antioxidant capacity of *Viola* × *wittrockiana* flowers.

Material and methods

Production, collection, selection and conservation of flower samples

The flowers used were produced in the vegetation house of the Federal University of Pampa - Campus Itaqui, Rio Grande do Sul State, Brazil. We used Purple Giant Swiss pansy seeds (*Viola* × *wittrockiana* Gams) from ISLA. They were sown in MACPLANT commercial substrate and received a nutritional solution with macro and micronutrients weekly so that there was no nutritional deficiency in the plants. They received daily irrigation and no pesticides were applied during cultivation. The flowers were harvested during the period from August to November 2017.

Whole flowers were selected in a perfect morphological state, being washed in running water and sanitized with 1% sodium hypochlorite solution (Silva et al., 2020). They were kept under freezing (-18°C) in a domestic freezer for fourteen days, except for the humidity and ash analyses that were performed soon after the harvest so that there were no possible interferences due to freezing. Ash analysis results were converted to dry mass.

Sample dehydration process and application of mathematical models to adjust the dehydration curve

For the dehydration process, fresh flowers were used at the end of the harvest, without going through the freezing process. The *Viola* × *wittrockiana* flowers were dried in a greenhouse with air circulation - SOLAB brand, model SL 102/480, at a temperature of 30°C, weighed every 15 min. until constant weight for approximately 3h, for subsequent application of the data in mathematical models. Each plot, consisting of one flower, was randomly allocated to a tray. Every fifteen minutes, three plots were removed from the study and their weights were quantified. Thus, three repetitions were applied for each time, totaling an experiment with 48 plots according to a completely randomized design. For the fit of the models and preparation of the dehydration curve, the nonlinear regression models were considered, according to Table 1. The equations (1) to (10) are commonly known as classical dehydration curve models and the equation (11) is the proposed Boltzmann model for dehydration curve modeling.

Table 1. Drying kinetics models for fitting the mass loss (*ML*) curve of *Viola* × *wittrockiana* flowers in relation to the dehydration time (*t*).

nº	Model designation	Model*
(1)	Page (Gasparin et al., 2017)	$ML = \exp(-k.t^n)$
(2)	Page (Modified) (Onwude et al., 2016)	$ML = \exp[-(k.t)^n]$
(3)	Henderson and Pabis (Costa et al., 2015)	$ML = a.\exp(-k.t)$
(4)	Midilli (Resende et al., 2018)	$ML = a.\exp(-k.t^n) + b.t$
(5)	Wang and Singh (Chen et al., 2015)	$ML = 1 + a.t + bt^2$
(6)	Newton (Santos, Figueirêdo, Queiroz, & Santos, 2017)	$ML = \exp(-k.t)$
(7)	Logarithmic (Chen et al., 2015)	$ML = a.\exp(-k.t) + c$
(8)	Two-term exponential (Onwude et al., 2016)	$ML = a.\exp(-k.t) + (1-a)exp(-k.a.t)$
(9)	Two-term (Santos et al., 2019)	$ML = a.\exp(-k_0.t) + b.\exp(-k_1.t)$
(10)	Thompson (Onwude et al., 2016)	$t = a\,.\ln(ML) + b\,.[\ln\,(ML)]^2$
(11)	Boltzmann (Heusser et al., 2021)	$ML = \frac{a}{1+\exp\left(\frac{t-b}{d}\right)} + c$

*The values k, n, a, b, c, d, k_0 and k_1 are the model parameters.

The estimation of the models parameters was obtained by the least squares method, which leads to a homogeneous equations system of whose solution was found by the Newton-Raphson numerical optimization method (Liska, Cirillo, Menezes, & Filho, 2020). The evaluation of the model that best fit to the data was performed through the relative mean error (*RME*), estimated mean error (*EME*), determination coefficients (R^2) and adjusted (R^2_a), whose expressions are given by

$$RME = \frac{100}{n}\sum_{i=1}^{n}\left(\frac{|ML-\widehat{ML}|}{ML}\right)$$

and

$$EME = \sqrt{\frac{\sum_{i=1}^{n}(ML-\widehat{ML})^2}{n-p}},$$

with n, the length sample and p the number of parameters in the fitted model in the Table 1 and $\widehat{ML}$ is the predicted mass loss by the fitted model.

Among the proposed models, the one with the best goodness of fit was provided with a confidence interval (*CI*) for the mean mass loss of the referred dehydration curve. To obtain the confidence interval, it is necessary to calculate the variance of the estimations of the parameters in the adjusted model, according to the procedure described by Silveira et al. (2020), given by

$$\hat{V}(\hat{\beta}) = (D'D)^{-1}\hat{\sigma}^2$$

where D is the matrix of the first partial derivatives of the model in relation to each model parameter, $\hat{\beta}$ is the model parameters vector and $\hat{\sigma}^2$, the mean square of the residuals, is estimated by

$$\hat{\sigma}^2 = \frac{\sum_{i=1}^{n}(ML-\widehat{ML}_i)^2}{n-p}.$$

The standard error for estimating a particular model parameter, $se(\hat{\beta}_i)$, is given by

$$se(\hat{\beta}_i) = \sqrt{\hat{V}(\hat{\beta}_i)}$$

being $\hat{V}(\hat{\beta}_i)$ an element of the main diagonal of the variance-covariance matrix. Thus, the 95% confidence interval for the parameter β_i of the model is defined as

$$CI_{95\%}(\beta_i) = \hat{\beta}_i \pm t_{(v;0.025)} \times se(\hat{\beta}_i)$$

where $t_{(v;0.025)}$ is the upper quantile of Student's t-distribution, considering α = 5% and the degrees of freedom $v = n - p$. In similar way, the confidence interval for the predicted mass loss $\widehat{y_0}$ is given by

$$CI_{95\%}(\widehat{y_0}) = \widehat{y_0} \pm t_{(v;0.025)} \times se(\widehat{y_0})$$

where

$$se(\widehat{y_0}) = \sqrt{F_0\hat{V}(\hat{\beta})F_0^T}$$

which F_0 is the gradient matrix evaluated on x_0 (Myers, Montgomery, Vining, & Robinson, 2012). To fit the models, as well as to obtain the goodness of fit criteria, we used the R statistical software (R Core Team, 2020).

Analysis of centesimal composition and calculation of energy value

A mix was created in which flowers from the entire collection period were mixed to analyze a sample that represented the entire collection. After this step, moisture, ash, lipids, proteins, fibers, carbohydrates by difference and energy value were quantified according to the methods proposed by Zenebon, Pascuet, and Tiglea (2008) and expressed as a percentage in edible flower. The energy value of flowers was calculated using conversion values for carbohydrates (4.0 Kcal), lipids (9.0 Kcal) and proteins (4.0 Kcal) (Silva et al., 2018).

Physical-chemical determinations

The physical-chemical determinations were carried out on the edible flowers. The total titratable acidity (TTA) was determined by titration, where the results were expressed in g of citric acid.100 g^{-1} of *Viola* × *wittrockiana* as described by Zenebon et al. (2008). The pH was determined through the use of a pH meter (model HOMIS/1317), previously calibrated with buffer solution 4 and 7. The total soluble solids were determined by reading directly from a refractometer (Abbé model DR 201/95) and the results were expressed in °Brix.

For the determination of total phenolic compounds and antioxidant activity, extracts of frozen flowers were prepared and after drying with 70 % acetone (Fernandes et al., 2017a). The determinations of the total phenolic compounds in frozen and dehydrated flowers were obtained through the standard curve of gallic acid with the equation $y= 0.5309\ x$, that is, where y is the absorbance of the extracts, 0.5309 is the angular coefficient, x is the concentration of total compounds expressed in mg gallic acid equivalents (GAE) per gram (mg GAE.g^{-1}), null intercept and R^2= 0.9928, performed based on the method described by Zardo, Zielinski, Alberti, and Nogueira (2015).

The antioxidant activity was determined in percentage of free radical inhibition DPPH (2,2-Diphenyl-1-picryl-hydrazyl) in frozen and dehydrated flowers, according to Moliner et al. (2019). A standard Trolox curve (6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid) was performed with the equation $y= 0.0037\ x + 0.5645$ that is, where y is the absorbance of the extracts, 0.0037 is the angular coefficient, x is the concentration antioxidant activity of expressed in μM Trolox g^{-1}, 0.5645 the intercept and R^2= 0.9992.

Results and discussion

Among the 11 models evaluated and according to the results obtained through the adjusted determination coefficient, estimated mean error and relative mean error, the Midilli model presented the best goodness of fit among the classical models for dehydration curve (Table 2). However, Boltzmann's proposed model presents better goodness of fit. Therefore, it is the most appropriate model to describe the process of mass loss of *Viola* × *wittrockiana*. It can be observed that for this model the adjusted determination coefficient was 98.46% and values higher than 98% means a good fitting of the models applied to represent the dehydration phenomenon. The relative mean error was 7.0768% and the estimated mean error was 0.0286 g and the relative mean error below 10% indicate satisfactory fitting (Resende, Oliveira, Costa, & Ferreira Júnior, 2018). Other authors also concluded that between the classical models, Midilli model was the best model to describe the curve of plant dehydration (Costa et al., 2016; Gasparin et al., 2017; Yildirim, 2018). It should be noted that the fitting of the mathematical model depends on the individual characteristics of each plant species, thus each plant should be studied individually In fact, Santos et al. (2019) in their studies with linseed oil concluded that the Two-term model was the most suitable. Chen et al. (2015) concluded that the Logarithmic and Two terms were the best fit to the experimental data of jujube (*Zizyphus jujuba* Miller) slices. On the other hand, Costa, Resende, Gonçalves, and Oliveira (2015) studied the drying of crambe fruits (*Crambe abyssinica*) and found Page model as the best fit. In a more general context, Onwude et al. (2016) reviewed the drying models of fruits and vegetables.

In summary, values obtained for the 11 fitted models showed that the adjusted determination coefficient range between 94.87 and 98.46%, the relative mean error varied between 7.0768 and 14.77% and the estimated mean error varied between 0.0286 and 17.56 g (Table 2). The determination coefficient is not sufficient to determine the most appropriate nonlinear regression model, and the estimated mean error and the relative mean error should be considered, which are used to indicate the deviation of the observed values to the curve estimated by the model (Gasparin et al., 2017). We can say that all models fit the data obtained during the dehydration process of the pansy flowers, however the Thompson model is the dehydration curve that most diverges from the data and the Boltzmann model is the best suitability to data (Table 2).

Table 2. Estimates of parameters of the fitted models and goodness of fit criteria R^2 (determination coefficient), R^2_a (adjusted determination coefficient), *RME* (Relative mean error) and *EME* (Estimated mean error) to *Viola* × *wittrockiana* flower dehydration data.

Model	Parameter	Estimates	Standard Error	*p value*	R^2	R^2_a	*RME*	*EME*	*r*
Newton	*k*	0.009504	0.000193	<0.0001	0.9698	0.9698	13.59	0.0428	0.9834*
Page	*k*	0.011891	0.002011	<0,0001	0.9668	0.9661	12.71	0.0425	0,9834*
	n	0.952312	0.035529	<0.0001					
Page (Modified)	*k*	0.009524	0.000201	<0.0001	0.9668	0.9661	12.72	0.0425	0,9834*
	n	0.952311	0.035529	<0.0001					
Thompson	*a*	-71.751	9.823	<0.0001	0.9498	0.9487	14.77	17.56	-0,9531*
	b	25.560	6.125	<0.0001					
Henderson and Pabis	*a*	0.997597	0.023125	<0.0001	0.9695	0.9689	13.57	0.0433	0.9833*
	k	0.009478	0.000313	<0.0001					
Logarithmic	*a*	0.971441	0.022669	<0.0001	0.9781	0.9771	8.47	0.0349	0.98899*
	k	0.013249	0.000878	<0.0001					
	c	0.105631	0.016881	<0.0001					
Two-terms	*a*	1.049612	0.021811	<0.0001	0.9805	0.9791	8.12	0.0332	0.9902*
	k_0	0.011034	0.000776	<0.0001					
	b	0.004677	0.009121	0.611					
	k_1	-0.012193	0.007718	0.121					
Two-terms Exponential	*a*	0.458688	0.088826	<0.0001	0.9678	0.9671	11.66	0.0405	0.9850*
	k	0.014736	0.002759	<0.0001					
Wang and Singh	*a*	-0.008287	0.000133	<0.0001	0.9790	0.9785	10.14	0.0353	0.9887*
	b	0.000020	0.000001	<0.0001					
Midilli	*a*	0.9405	0.03093	<0.0001	0.9843	0.9832	7.5281	0.0299	0.9921*
	k	0.002115	0.000997	0.0396					
	b	0.0006224	0.000063	<0.0001					
	n	1.369	0.09996	<0.0001					
Boltzmann	*a*	0.9990	0.1185	<0.0001	0.9588	0.9846	7.0768	0.0286	0.9927*
	b	46.4726	8.7506	<0.0001					
	d	36.3589	3.8967	<0.0001					
	c	0.1638	0.0098	<0.0001					

*Hypothesis test of Pearson's correlation parameter (*r*), whose null hypothesis is that the correlation between the observed mass loss and the predicted mean mass loss is null. The *indicates that the null hypothesis was rejected with a 5% significance level.

Figure 1 presents the predicted mass loss by the Midilli model during the different dehydration time of *Viola* × *wittrockiana*, with the respective point estimates and 95% confidence interval for mean mass loss or final weight. It shows that, in the initial stages of the dehydration process, a loss of mass (free water) of 0.8 g 170 min.$^{-1}$ (80% of wet weight) occurs, after which time the loss of mass stabilizes. When determining a confidence interval for the fitted model, it can be observed that all data are between the upper and lower limits of the calculated confidence interval, as follows: with 95% confidence, the average wet mass loss of the flower *Viola* × *wittrockiana* is between 0.15 and 0.25 g, considering approximately the dehydration time of approximately 170 min under this study conditions. On the proposed model (Boltzmann), the *a* parameter means that the initial water loss is 0.99 g and reaches a lower level of 0.16 g (parameter *c,* whose $CI_{(95\%)}$ (c) = (0.14 g; 0.18 g)).

In addition and different from the classical models, the Boltzmann model presents an inflection point (parameter *b*), which indicates that the maximum rate of mass loss of *Viola* × *wittrockiana* occurs in 46.5 min. ($CI_{95\%}$ (b) = (18.9 min.; 60 min.)), whose mass loss is 0.66 g ($ML = a/2 + c$). From that point onwards the leaf continues to lose mass, but decelerating until reaching the mass loss limit. The 95% confidence interval for mean mass loss by Boltzmann model showed similar behavior to Midilli model, with slightly narrower interval. Therefore, the results show that, in addition to the best goodness of fit indicators, the Boltzmann model provides measures of practical interest through the estimates of its parameters, which does not occur with the classical models. Thus, the drying time of *Viola* × *wittrockiana* petals can be obtained in order to preserve the best physical-chemical, biological and nutritional characteristics and the time found is consistent with the studies of phenolic compounds carried out by Silva et al. (2020), who found that the time of 3h provides the best conditions for the extraction of these compounds.

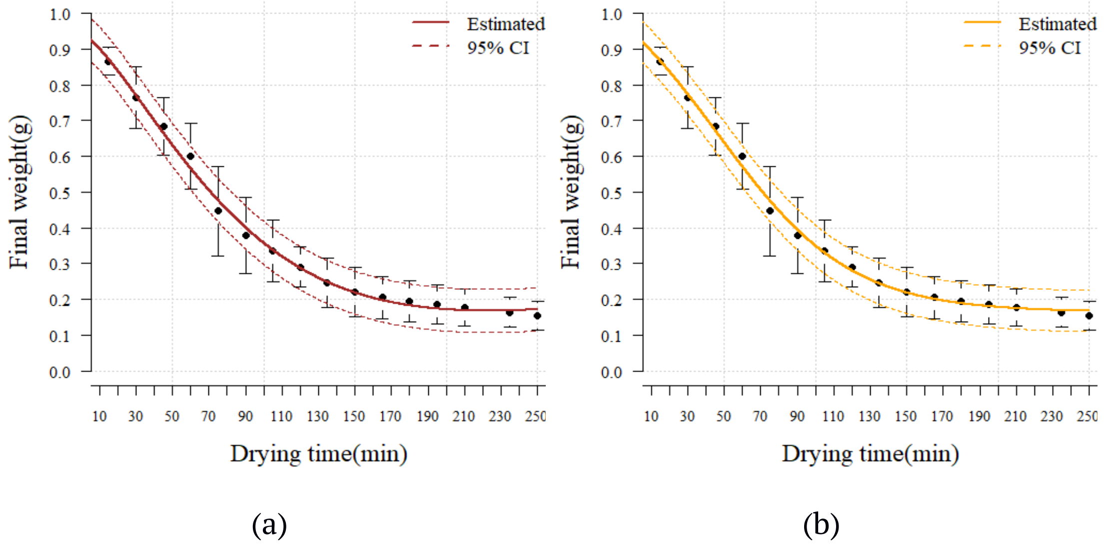

Figure 1. Midilli (a) and Boltzmann (b) models fitted to dehydration data of edible parts of *Viola* × *wittrockiana*, with the respective point estimates and 95% confidence interval for the mean estimates of the final weight (mass loss) of edible parts.

Table 3 shows the centesimal composition of the edible flowers of the species *Viola* × *wittrockiana* with experimental design description given on previous section. A moisture content of around 84.69 g per 100 g of wet matter was found, a value close to that found by Silva et al. (2020), which was 87.76 g per 100 g of wet matter. These values represent a considerable amount of water in the flowers, which contributes to the good intestinal functioning, that is, they help in body hydration, as water is essential for the performance of several physiological functions (digestion, absorption and excretion) and can be consumed as part of the diet (Franzen, Oliveira, Lidório, Menegaes, & Fries, 2019). According to data found in the literature, the moisture content of fresh flowers can vary from 60 to 95%, carbohydrates from 8 to 9.5% (Franzen et al., 2016), which corroborates with our study. However, Silva et al. (2020) found 80.27 g per 100 g of dry matter for carbohydrates, values much higher than those found in this study. In this study, 0.4 g per 100 g of dry matter was found for lipids, values close to that found by Fernandes et al. (2019a), which was 0.45 g per 100 g of edible flower, and lower than that found by Silva et al. (2020), which was 1.67 g per 100 g of flower dry mass. Foods with lipid concentrations below 1% can be indicated for weight reduction diets, since they can increase the consumption of good quality fats and contribute to the prevention of cardiovascular diseases, in addition to being values normally found in most fruits, vegetables and edible flowers (Fernandes, Casal, Pereira, Saraiva, & Ramalhosa, 2017b).

Table 3. Centesimal composition of flowers of the specie *Viola* × *wittrockiana*.

Component	Result*
Humidity [a]	84.69 ± 1.60
Carbohydrates [b]	8.76 ± 0.01
Lipids [b]	0.40 ± 0.33
Proteins [b]	2.51 ± 0.37
Crude fiber [b]	2.41 ± 0.37
Ash [b]	1.23 ± 0.03
Caloric Value (Kcal) [c]	48.68 ± 0.01

*Mean ± standard deviation of three replicas; [a] Content expressed in g per 100 g of wet matter; [b] Content expressed in g per 100 g of dry matter; [c] Result expressed in Kcal per 100 g of dry matter.

A protein content of 2.51 g per 100 g of dry mass was observed (Table 3), corroborating Fernandes et al. (2019a), who reported that this is a low protein source food. However, Silva et al. (2020) found 10.14 $g.100 g^{-1}$ of flower dry mass for proteins, values above those found in this study. These authors pointed out that flowers, in addition to decorating dishes, can be a source of protein and complement the diet.

The flowers studied cannot be considered a source of fiber, as according to RDC No. 54, for a given food to be considered a source of fiber, it must have at least 3 g of fiber 100 g^{-1} (solid) (Franzen et al., 2016).

We found ash contents (1.23 $g.100 g^{-1}$ of dry mass), similar to the found by Fernandes et al. (2019a), whose range values are 0.92 to 1.16 $g.100 g^{-1}$ in different colors of species *Viola* × *wittrockiana*. Silva et al. (2020)

found 7.92 g 100 g^{-1} of dry mass. In the work from Fernandes et al. (2017b), minerals such as phosphorus, potassium, calcium, manganese, iron, copper, magnesium and zinc were characterized, which are present in the quantification of ash content.

The flowers studied had a low caloric value (48.68 Kcal per 100 g of dry mass), thus being able to be included in low calorie diets (Table 3) (Franzen et al., 2019). Similar values were found by Fernandes et al. (2019 b) and very low when compared to data from Silva et al. (2020), which was 376.67 kcal per 100 g of dry mass.

It is worth mentioning that variations in environmental factors such as temperature, relative humidity, luminosity, characteristics of the soil in which they were planted, in addition to supplementation with a nutrient solution of macro and micronutrients and also of cultures, can explain the differences found in the proximate composition of this study in compared to the other studies cited (Morais et al., 2020).

According to Table 4, it can be seen that the content of total phenolic compounds found in this study are within the range of values found by Silva et al. (2020), which was from 73 to 1033.5 mg of gallic acid equivalent per 100 g sample. Gonçalves et al. (2019b) and Silva et al. (2020) found that the highest concentration of phenolic compounds found in *Viola × wittrockiana* was in the purple (darker) flowers when compared to lighter colors. According to Dantas et al. (2019), different results can be found for the levels of phenolic compounds due to several factors, such as abiotic and biotic factors, type of crop management, soil, climate, temperature, pH, light, species and variety, among others. Our results in range were similar to those found by Li et al. (2014) in their studies with 51 species of edible flowers. In addition, they found a high correlation between phenolic compounds and antioxidant capacity, and such studies provide new information for nutritionists, food policy makers and consumers.

Table 4. Results of the determination of total phenolic compounds and antioxidant activity on *Viola × wittrockiana* edible flower.

Compound	Frozen	Dehydrated
Phenolic Compounds (mg GAE 100 g^{-1})	423.00 ± 0.06	301.00 ± 0.01
Antioxidant Activity (% inhibition)	90.67 ± 0.07	94.93 ± 0.13
Antioxidant Activity (mg Trolox 100 g^{-1})	44.00 ± 0.07	49.00 ± 0.13

Mean ± standard deviation of three replicas.

When comparing the results of total phenolic compounds of the frozen flowers (dry mass) with the dehydrated flowers, a reduction in the content of these compounds is observed, due to the hot air drying method affecting the quality of the flowers, mainly in terms of color, since this is related to the presence of phenolic compounds, in addition to causing nutritional and biochemical changes (Matos & Fonseca, 2020).

Regarding antioxidant activity, it can occur through several mechanisms of action, for this reason more than one evaluation method was used (Morais et al., 2020). According to Silva et al. (2020) the percentage of inhibition of the DPPH radical in *Viola × wittrockiana* flowers was on average 90%, regardless of color, which corroborates the data found in this study. This indicates that the flowers of *Viola × wittrockiana* have high antioxidant activity in relation to the capture of the DPPH radical and the Trolox method. In this way, it can be used in food, since it has properties with health benefits (Morais et al., 2020). In studies conducted by Moliner et al. (2019), the flowers of *Viola × wittrockiana* were shown to be a good source of phenolic compounds, high level of bioactivity and suggest that the extract of its leaves may be an interesting candidate to prevent disorders of the Central Nervous System.

The antioxidant properties of *Viola × wittrockiana* flowers are related to the presence of phenolic compounds and ascorbic acid and tocopherols. This study found an increase in antioxidant activity in dehydrated flowers than in frozen flowers, which demonstrates that other compounds are involved in the antioxidant capacity and that the drying process can cause biochemical and nutritional changes (González-Barrio, Periago, Luna-Recio, Garcia-Alonso, & Navarro-González, 2018; Morais et al., 2020). In this sense, the dehydration method can be used in order to obtain a product with a higher concentration of phytochemical compounds, in addition to allowing its application in various types of products.

The mean results obtained from physical-chemical determinations of the fresh flowers of *Viola × wittrockiana* are described in Table 5. The samples analyzed showed a low acidity content, 0.24 g citric acid 100 g^{-1} similar to that found by Souza, Jung, Benedicto, and Bosco (2021) in gladiolus flowers, with 0.21 mean percent content. As reported by these authors, gladiolus flowers can be considered low acid vegetables, showing greater potential for consumer acceptance. The samples of flowers analyzed showed a pH close to neutrality 6.28 as well as the samples of Viola tricolor. In fresh foods, a slight acidity usually occurs, as found by Gonçalves et al. (2019a), with a pH of 7.17 in flowers *in Natura*. The low acidity and the pH close to neutrality are factors that may justify the high perishability of this type of food, since the presence of organic acids contributes to the post-harvest quality of plant tissues (Fernandes et al., 2019b). The flowers had a low content of total soluble solids (7.25°Brix), this value gives us an indication of the amount of sugars found in a product, as reported by Souza et al. (2021), who found TSS values in the range of 4.9 to 5.8 in four species of gladiolus flowers, indicating that these present low sweetness.

Table 5. Physical-chemical characteristics of *Viola* × *wittrockiana* edible flowers.

Properties	Value
Acidity (g of citric acid 100 g^{-1})	0.24 ± 0.03
pH	6.28 ± 0.04
TSS (°Brix)	7.25 ± 0.01

Mean ± standard deviation of three replicas. TSS: total soluble solids.

We emphasize that more studies with edible flowers of *Viola* × *wittrockiana* are required. Some studies that explore nutritional, chemical and biological characteristics were found, but none that study the drying kinetics of *Viola* × *wittrockiana*. As reported in some works, the drying kinetics, as well as the physical-chemical characteristics, are linked to the type of product and, in this sense, the influence of temperature or other experimental conditions that eventually influence in the characterization of the edible flowers of *Viola* × *wittrockiana* can be studied. Alternative views regarding the modeling of the drying process, as done by Beigi and Ahmadi (2019) in the proposition of artificial neural networks, and consumer preference (Chen & Wei, 2017; Rodrigues et al., 2017) are viable.

Conclusion

Regarding the determination of a dehydration curve, the Boltzmann model showed best goodness of fit for *Viola* × *wittrockiana* mass loss and through this model the maximum mass loss occurs with 0.16 g, whose 95% confidence interval is 0.14 to 0.18 g, the maximum rate of mass loss of *Viola* × *wittrockiana* occurs in 46.7 min. ($CI_{95\%}$ (b) = (18.9 min.; 60 min.)) whose mass loss is 0.66 g. The 95% confidence interval for the mean mass loss of the flower of *Viola* × *wittrockiana* determines that the average loss varies between 0.15 and 0.25 g, considering the dehydration time of approximately 170 min. The results point out that the optimum drying time of *Viola* × *wittrockiana* flowers, in order to preserve the best physical-chemical, biological and nutritional characteristics, occurs before the time found in the literature (3h), which represents a time gain in the drying process. The flowers of *Viola* × *wittrockiana* analysed showed high moisture content, which may be related to their high perishability, requiring further study to reach a more accurate conclusion and cannot be considered a source of fiber and lipids. About phenolic compounds and antioxidant activity, before and after dehydration, it was possible to observe the presence of phenolic compounds and also the very relevant antioxidant activity in flowers, but further studies are needed to verify which compounds are involved in the antioxidant activity.

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