https://doi.org/10.17221/139/2023-CJFS

Physicochemical and antioxidant evaluation of watercress (*Rorippa nasturtium aquaticum* L.) leaf extracts

*Edgar Daniel Cabrera-Domínguez[1], Jesús Rodríguez-Miranda[1], Reyna Nallely Falfán-Cortés[2], Enrique Ramirez-Figueroa[1], Juan Gabriel Torruco-Uco[1], Betsabé Hernández-Santos[1]**

[1]*Departamento de Ingeniería Química y Bioquímica, Tecnológico Nacional de México/Instituto Tecnológico de Tuxtepec, Tuxtepec, Oaxaca, México*

[2]*Centro de Investigaciones Químicas, Universidad Autónoma del Estado de Hidalgo, Mineral de la Reforma, Hidalgo, México*

**Corresponding author: bethershan19@gmail.com , betsabe.hs@tuxtepec.tecnm.mx*

Citation: Cabrera-Domínguez E.D., Rodríguez-Miranda J., Falfán-Cortés R.N., Ramirez-Figueroa E., Torruco-Uco J.G., Hernández-Santos B. (2025): Physicochemical and antioxidant evaluation of watercress (*Rorippa nasturtium aquaticum* L.) leaf extracts. Czech J. Food Sci., 43: 274–282.

Abstract: This research aimed to evaluate the type of solvent (80% methanol, ethanol, and water), solute/solvent ratio (1 : 10 and 1 : 15 w/v), maceration time (0 h, 24 h and 7 d) and stage of leaf maturity [vegetative (VW) and generative (GW)] on the physicochemical and antioxidant properties of watercress leaf extracts. The leaf was characterised by determining the chemical composition, the phytochemical profile, and the colour. The GW presented the highest moisture content [93.25 g·(100 g)$^{-1}$], carbohydrates [70.74 g·(100 g)$^{-1}$], and lightness (L^* = 59.66), and the presence of alkaloids, phytosterols, phenols, and flavonoids. VW had the highest protein content [26.52 g·(100 g)$^{-1}$] and the lowest presence of phytochemicals. The best solvent for the extraction was distilled water at a 1 : 15 w/v ratio, GW at 24 h rest centrifuged at 2 300 × g for 15 min, obtaining the highest values of phenols [2 077 mg GAE·(100 g)$^{-1}$], of dust and an inhibition power of 85.09% by the 2,2'-azino-bis (3-ethylbenzothiazoline-6-sulfonic acid) radical cation (ABTS+) radical method. Therefore, cress leaves in the generative stage can be considered a potential source of bioactive compounds, and using water as an extracting agent for these compounds makes it a viable and economical method to be used in the food industry, and in addition, to be friendly to the environment.

Keywords: antioxidant capacity; extraction; maceration; phytochemical compounds; wild plants

Recently, in Mexico and internationally, the number of chronic degenerative diseases has been increasing, affecting adults as well as children (Ávila-Escalante et al. 2020). This is mainly a consequence of poor diet and low consumption of foods with nutraceutical compounds. It is the reason why alternatives are sought in natural foods that contain 30 substances beneficial to health. Watercress (*Rorippa nasturtium aquaticum* L.) belonging to the family *Brassicaceae* is a plant that can grow wild in swampy places in Mexico; it is cultivated commercially for its edible leaves in the vegetative state (green), since the leaves in the generative state are discarded for their physical appearance (yellow and withered) (Al-Snafi 2020).

However, in both states of maturity of the leaves, this plant contains important compounds such as proteins, vitamins (A, B1, B2, B3, C, E), minerals (Fe, Ca, K), and bioactive compounds, among which are included phenolic acids, flavonoids (catechins, quercetins, flavonols), glucosinolates, isothiocyanates, terpenoids and tannins, which have been identified in watercress by various authors (Pinela et al. 2020), and which are

https://doi.org/10.17221/139/2023-CJFS

responsible for the antioxidant capacity, the main function of which is to help prevent various chronic degenerative diseases (Al-Snafi 2020).

In this sense, to extract these bioactive compounds with biological activity, it is important to establish a viable, practical, environmentally friendly, and economic extraction method. In recent years, various extraction methods have been used for this purpose; these methods include conventional methods such as Soxhlet extraction, percolation, and maceration, as well as unconventional methods like ultrasound, microwaves, and high hydrostatic pressures. Another factor in the extraction of bioactive compounds is the use of a solvent, since it has been reported that ethanol, methanol, acetone and their mixtures with water at different ratios have had favourable results. However, there is no defined method and solvent as this will depend, among other factors, on the chemical structure of the compounds to be extracted, the concentration of the solvent, temperature, rest time with the sample, and mass-solvent ratio, as well as on the nature of the sample. Therefore, the aim of this investigation was to evaluate the impact of the type and ratio of solvent (80% methanol, ethanol, and water, 1 : 10 and 1 : 15 w/v), maceration time (0 h, 24 h, and 7 d), and stage of leaf maturity (vegetative and generative) on the physicochemical and antioxidant properties of watercress (*Rorippa nasturtium aquaticum* L.) leaf extracts.

MATERIAL AND METHODS

Collection and selection of raw material

The watercress leaves were purchased from the local market of San Juan Bautista Tuxtepec, Oaxaca, Mexico. Two batches of cress leaves were obtained depending on the stage of maturity. The first batch comprised leaves in the vegetative growth stage (VW) which presented intense green colour because they are new leaves produced by the plants during growth for root and foliage development. The second batch consisted of leaves in the generative growth stage (GW) that were yellow in colour; this characteristic is a consequence of the fact that the plant enters a stage of reproduction.

Physicochemical characterisation of the leaves

The physicochemical properties were determined according to the following AOAC (2005) methods (pH, soluble solids, moisture, ash, fats, fibre, proteins and total carbohydrates by difference). The energy content and phytochemical profile were determined according to Rodríguez-Miranda et al. (2022). Colour was determined using a HunterLab tristimulus colorimeter (model WR-10QC, 45/0L, Reston, Virginia, USA) determining the parameters of luminosity [L^* = 100 light/0 dark), a^* (+ red/ − green), b^* (+ yellow/− blue), chromaticity ($C^* = ((a^{*2} + b^{*2})^{1/2})$) and hue angle ($h^\circ = ((a^{*2} + b^{*2})^{1/2})$)].

Conditioning the leaves and obtaining leaf powder

The leaves were dried at 60 ± 2 °C for 4 h, ground and an 80 mesh (180 μm) sieve was used.

Obtaining the extracts of watercress leaves

Leaf extracts in VW and GW stages were made by maceration at 1 : 10 and 1 : 15 w/v (solute/solvent) with three different solvents (80% methanol, ethanol, and water, respectively), at different rest times [0 h (T0), 24 h (24h) and 7 days (7d)] and centrifuging at 6 100 × g for 10 min and 2 300 × g for 15 min. An extract was also made by infusion in distilled water (98 °C for 15 min) (Figure 1).

Characterisation of the extracts

Total phenols. An amount 250 μL of the extract, 625 μL of the 10% Folin-Ciocalteu reagent, and 500 μL of 7.5% sodium carbonate solution were taken. It was kept in the dark for 120 min and the absorbance was measured at 760 nm (Rodríguez-Miranda et al. 2022). The values of total phenolic compounds were expressed as mg gallic acid equivalents GAE·(100 g)$^{-1}$ of watercress powder.

Total flavonoids. Two standards were used, catechin and quercetin. For catechin, 1 mL of the extract, 100 μL of 5% sodium nitrite, 100 μL of 10% aluminium chloride, and 200 μL of 4M sodium hydroxide were allowed to react for 5 min and read at a wavelength of 510 nm, expressing the results in mg catechin equivalents CE·(100 g)$^{-1}$ of watercress powder. For quercetin, 1 mL of the extract and 100 μL of 10% aluminium chloride were taken. The absorbance was read at 430 nm, expressing the results in mg quercetin equivalents QE·(100 g)$^{-1}$ of watercress powder. The results were added to obtain total flavonoids and expressed in mg·(100 g)$^{-1}$ of watercress powder (Rodríguez-Miranda et al. 2022).

Antioxidant capacity

DPPH*. The antioxidant capacity was measured by two methods: 1,1-diphenyl-2-picrylhydrazyl (DPPH)-2,2-diphenyl-1-picrylhydrazyl (DPPH*), according to the methodology described by Rodríguez-Miranda et al. (2022), which is based on the reduction of the absorbance of the radical DPPH* 100 μM (3.9 mL) dissolved

https://doi.org/10.17221/139/2023-CJFS

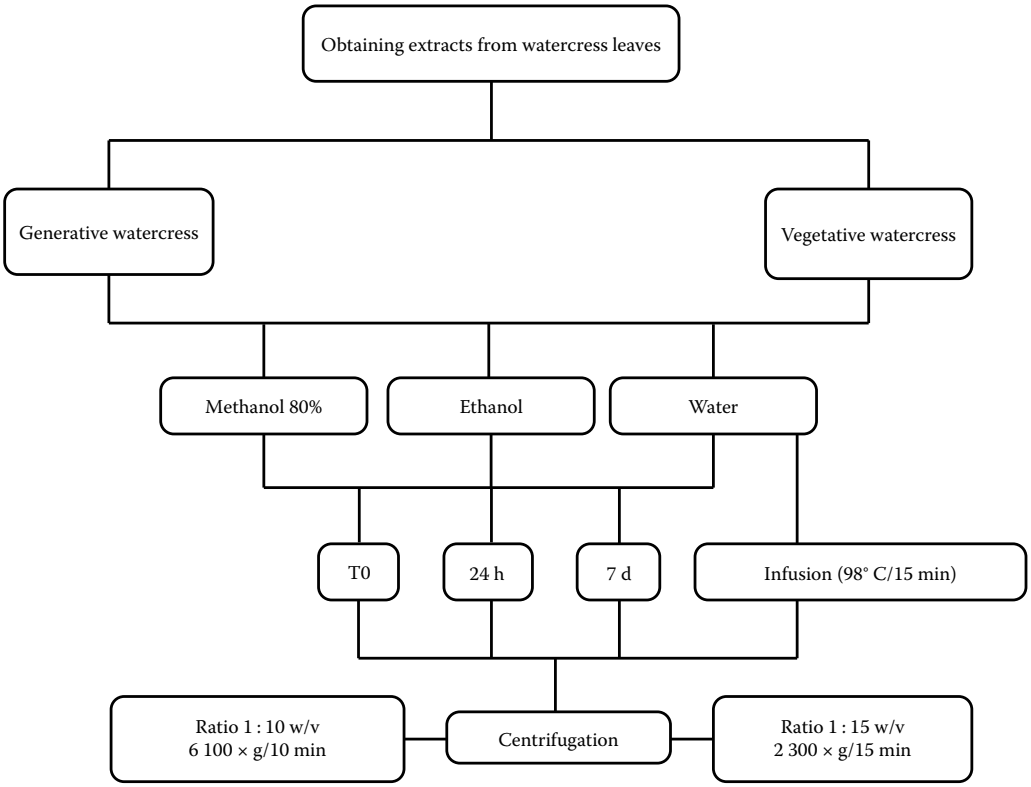

Figure 1. Diagram for obtaining watercress leaves extracts by maceration depending on the state of maturity, using different solvents

in methanol adjusting to an absorbance of 0.7 ± 0.02, at 515 nm. 50 µL of the sample or standard and 1 050 µL of the radical were used, and kept in the dark for 30 min. The results were expressed in % antiradical activity of the watercress leaf extract.

ABTS+ radical. The ABTS+ radical (7 mM) solution was prepared with potassium persulfate (2.45 mM) (Almulaiky et al. 2020), when 1 mL of the ABTS+ radical was diluted with 45 mL of ethanol until obtaining an approximate absorbance of 0.7 ± 0.02 at 732 nm. An aliquot of 50 µL was taken from the extract and 1050 µL of the ABTS+ radical solution was added. It was kept in the dark for 30 min and its absorbance was measured at 732 nm. The results were expressed in % antiradical activity of the watercress leaf extract.

Statistical analysis

The results are the means of three replicates ± standard deviation. A one-way ANOVA and a mean comparison test were performed using the Tukey method with a confidence level of 95%, using the Statistica software (version 10, StatSoft, Inc., 2011, USA).

RESULTS AND DISCUSSION

Physicochemical characterisation of watercress leaves

The major component of the watercress leaves is moisture, when significant differences ($P < 0.05$) were obtained in different stages of maturity (Table 1). This increase in moisture is due to the mature leaf absorption of moisture from the environment, as the plant grows in water. So, most of the plant weight is moisture due to such water absorption, and also due to the loss of turgor stopping the plant transpiration mechanism, which causes them to lose their rigidity; the bound water contained in their compounds is released as a consequence of their degradation (Larridon et al. 2020).

They did not present any significant differences ($P > 0.05$) in the ash and fat content (Table 1). These results are lower than those reported by Pinela et al. (2020) in watercress leaves (1.04 g·(100 g)$^{-1}$ of ash and fats 2.46 g·(100 g)$^{-1}$), due to the agronomic conditions of the crop.

On the other hand, high levels of the protein content were found in both GW and VW (Table 1). However, significant differences ($P < 0.05$) were observed

https://doi.org/10.17221/139/2023-CJFS

Table 1. Physicochemical characterisation of watercress leaves in generative (GW) and vegetative (VW) stages

Parameters	Samples	
	GW	VW
pH	6.82 ± 0.00[a]	6.53 ± 0.01[b]
Soluble solids (°Brix)	4.00 ± 0.00[b]	5.00 ± 0.00[a]
Moisture [g·(100 g)$^{-1}$]†	93.25 ± 0.20[a]	90.42 ± 0.21[b]
Ash [g·(100 g)$^{-1}$]	1.18 ± 0.11[a]	1.35 ± 0.10[a]
Fat [g·(100 g)$^{-1}$]	3.69 ± 0.30[a]	3.49 ± 0.37[a]
Proteins [g·(100 g)$^{-1}$]	24.37 ± 0.05[b]	26.52 ± 0.91[a]
Fibre [g·(100 g)$^{-1}$]	15.51 ± 0.40[a]	15.09 ± 0.07[a]
Carbohydrates [g·(100 g)$^{-1}$]	70.74 ± 0.44[a]	68.62 ± 0.62[b]
Total energy content [Kcal·(100 g)$^{-1}$]	413.68 ± 1.11[a]	412.02 ± 2.22[a]
L^*	59.66 ± 0.28[a]	58.31 ± 0.24[b]
a^*	1.71 ± 0.67[a]	–4.51 ± 0.18[b]
b^*	23.88 ± 0.53[a]	21.63 ± 0.42[b]
C^*	23.95 ± 1.50[a]	22.10 ± 0.38[b]
h°	85.92 ± 1.51[a]	78.23 ± 0.67[b]

Data expressed as the mean of three repetitions ± standard deviation; [a,b]different letters between rows indicate a significant difference ($P < 0.05$); † values expressed on a wet weight; L^* – luminosity; a^* – +red/–green; b^* – +yellow/–blue; C^* – chromaticity, h° – hue angle

between them. This is a consequence of the protein degradation due to the effect of the stage of maturity, thus producing other types of compounds such as secondary metabolites (flavonoids and carotenoids) and decreasing proteins due to leaf senescence during the degradation of chloroplasts for the formation of gerontoplasts (Larridon et al. 2020). Pinela et al. (2020) observed lower values in watercress leaves proteins (23.18 g·(100 g)$^{-1}$) than those of this investigation.

In the fibre content there were no significant differences ($P > 0.05$) between the GW and VW, which can be explained by the carbohydrates that constitute the structure of the leaves. The stage of maturity does not affect the fibre, and therefore the same content was found in both batches of watercress leaves.

The fibre content was higher than that reported by Pereira et al. (2011) in wild watercress green leaves (26.08 g·(100 g)$^{-1}$). This may be due to the chemical structure of the leaves of the plants, as well as to the season (spring or winter) when the raw material was collected. Carbohydrates presented higher values in GW as a consequence of the presence of lower values of ash, fat, and protein compared to VW (70.74 g·(100 g)$^{-1}$ and 68.62 g·(100 g)$^{-1}$, respectively).

The energy content was below (Table 1) the level than what is proposed by the Recommended Dietary Allowances (RDA in 2022). The calories suggested for daily consumption according to age and gender are as follows: children (1 300–2 000 Kcal), women (1 400–2 200 Kcal) and men (2 200–3 000 Kcal); therefore, the consumption of these leaves can be included in the daily diet, obtaining part of the calories necessary for our daily activities.

Significant differences ($P < 0.05$) were observed in the analysed colour parameters [L^*, a^*, b^*, C^*, and h° (Table 1)]. The values suggest that the WG presents a light brown colour (Figure 2b), while the VW presents a greyish-green colour (Figure 2a). This is because at the beginning of drying, the leaves of GW were yellow and those of VW were intense green. This phenomenon is known as leaf senescence and it results in the transformation of the plant cell chloroplasts to gerontoplasts, and subsequently in the degradation of chlorophyll, producing carotenoids and flavonoids (characteristic of yellow-orange colour).

In the phytochemical profile, the sample that presented the highest colour intensities during the qualitative tests was the GW, especially in the alkaloid, phytosterol, phenol, and flavonoid tests (Table 2). Alkaloids are compounds to which therapeutic potentials have been attributed, e.g. against multiple sclerosis, rheumatoid arthritis, and they also show anti-inflammatory properties (Núñez et al. 2018; Xu et al. 2020) while phytosterols are responsible for reducing lipids in the body. Some properties such as antitumor, anti-inflammatory, fungicidal, and bactericidal ones are also attributed to these compounds (Nattagh-Eshtivani et al. 2022). On the other hand, polyphenol compounds that encompass a large number of compounds, among others phenolic acids, hydroxybenzoic acids, and flavonoids, are responsible for the antioxidant and antimicrobial capacity (Zhang et al. 2022). It has been reported that watercress contains a large variety of beneficial compounds, such as polyphenols, glucosinolates, isothiocyanates, carotenoids, which are responsible for the antioxidant capacity, and thus for the reduction of chronic degenerative diseases like cancer, diabetes, cardiovascular diseases (Engelen-Eigles et al. 2006; Aires et al. 2013; Boligon et al. 2013; Klimek-Szczykutowicz et al. 2018; Chis et al. 2020).

Characterisation of the extracts

Total phenols. Significant differences ($P < 0.05$) were observed between the extracts. In the extracts

https://doi.org/10.17221/139/2023-CJFS

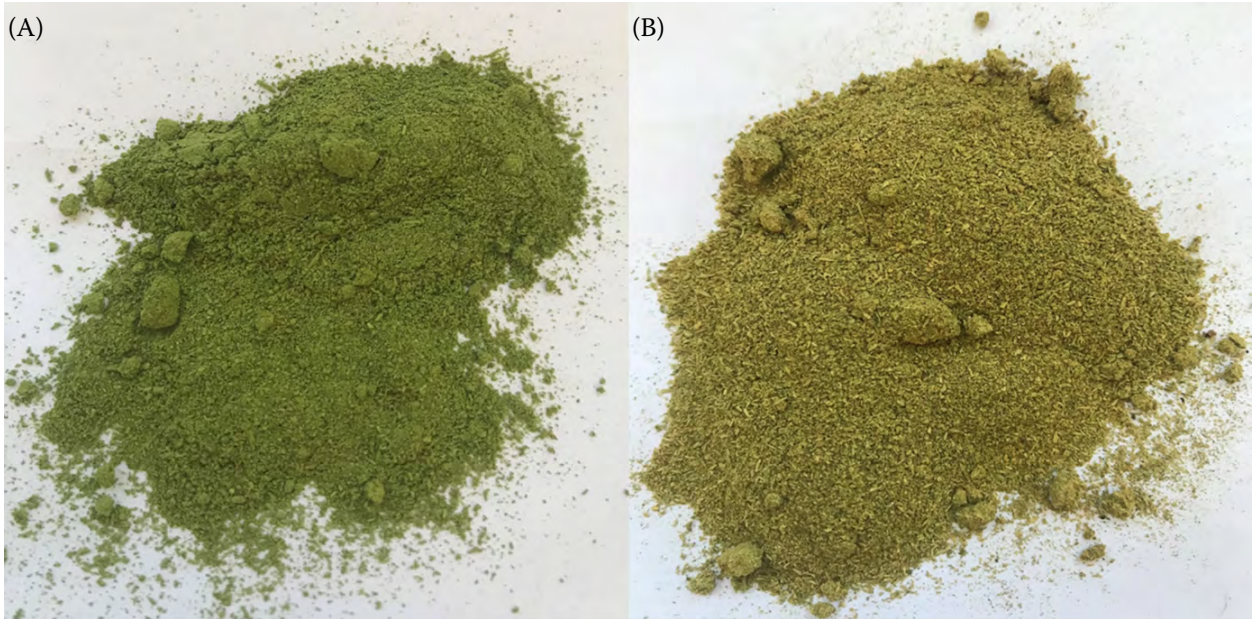

Figure 2. (A) Vegetative watercress leaf powder sample and (B) generative watercress leaf powder sample

(VW and GW) obtained at the watercress leaf powder to solvent ratio of 1 : 10 w/v, methanolic and aqueous extracts with the rest for 7 d and 24 h, presented the highest amount of phenols (2 522 mg GAE·(100 g)$^{-1}$ and 2 435 mg GAE·(100 g)$^{-1}$, respectively) (Figure 3a). While the ethanolic extracts were the ones with the lowest amount of phenolic compounds. This may be due to the low affinity of the bioactive compounds present in watercress to the solvent (Figure 3a). On the other hand, when the 1 : 15 w/v ratio was used, the aqueous extracts with 24 h of rest (VW and GW) presented the highest content of polyphenols. A similar effect was observed by Paladino and Zuritz (2011), who reported the highest extraction using water as the solvent, followed by methanol and ethanol in the last place.

In the case of the infusion treatment, the highest phenolic content was expected to be obtained in this treatment (Figure 3a) since Sánchez-Chino et al. (2019) reported that more phenolic compounds are extracted by the infusion method applied for the maceration using water as a solvent, but everything will also

Table 2. Phytochemical profile of watercress leaves as a function of maturity stage

Phytochemical compound	Method	Sample	
		GW	VW
Alkaloids	Dragendorff	+++++	+++
	Hager's	+++++	+++
Carbohydrates	Benedict's	+	+
Glycosides	Borntrager's	+	+
Saponins	foam formation	+	+
Phytosterols	Salkowski	+++++	+++
	Liebermann-Burchard	+++++	+++
Phenols	ferric chloride	+++++	+++
Flavonoids	alkaline reagent	+++++	+++
Terpenoids	copper acetate	+	+

Data expressed as the mean of three repetitions ± standard deviation; + indicates presence of phytochemicals; +++ shows a moderate concentration; +++++ shows a high concentration VW – vegetative watercress; GW – generative watercress

https://doi.org/10.17221/139/2023-CJFS

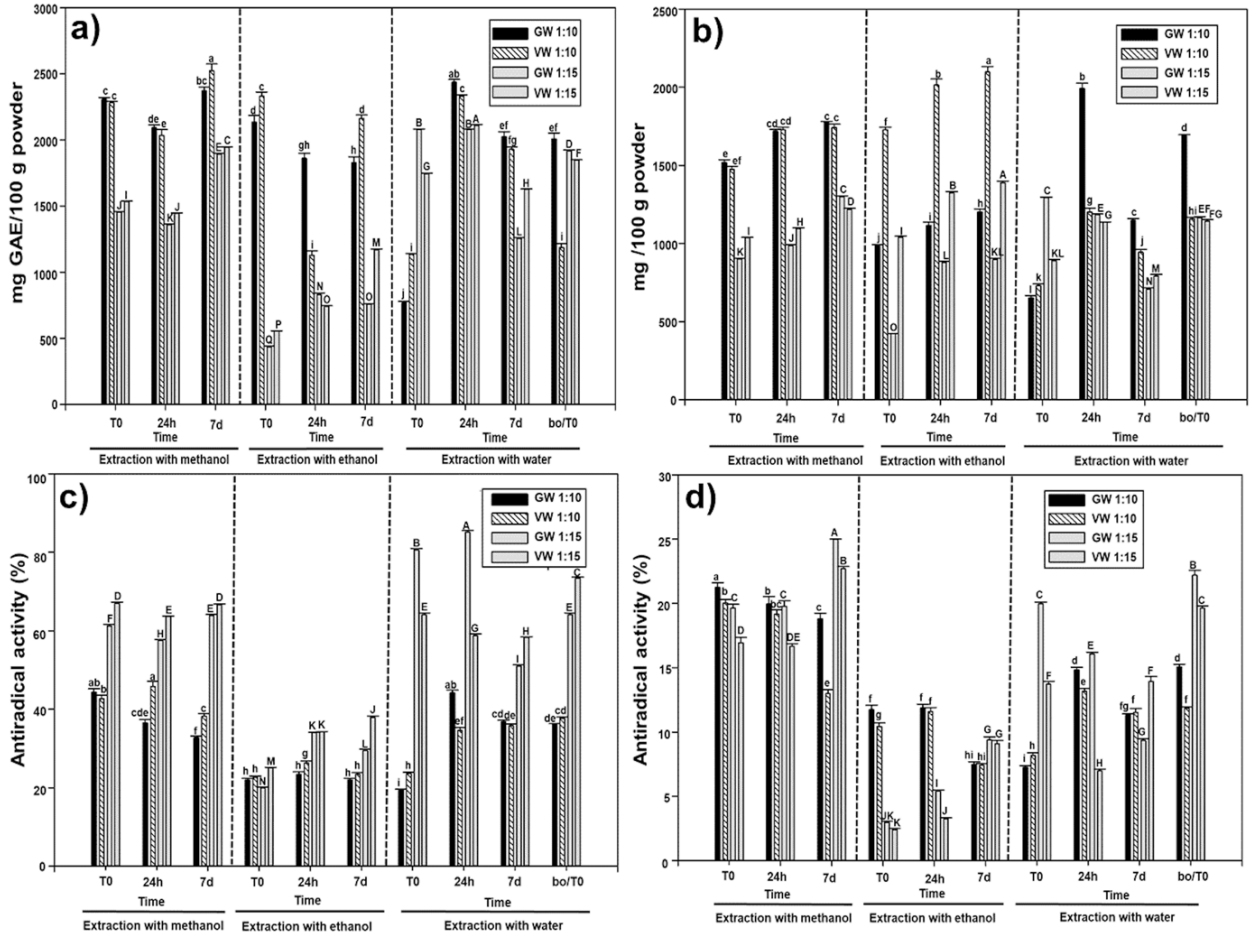

Figure 3. (A) Total phenols; (B) total flavonoids; antiradical activity: (C) ABTS+ radical; and (D) DPPH* in the different extracts of watercress leaves obtained by infusion in boiling water (bo) or maceration at different maturity stages—generative (GW) and vegetative (VW) – using different solvents (80% methanol, ethanol, and water), solute/solvent ratios (1 : 10 and 1 : 15 w/v), and resting times (T0 = zero time, 24 h, and 7 d)

depend on the chemical composition of the raw material. Mazandarani et al. (2013) obtained the values of 803–935 mg gallic acid equivalent (GAE)·(100 g)$^{-1}$ for VW extract and 650–765 mg GAE(100 g)$^{-1}$ for GW extract, concluding that these variations are due to different concentrations of the used raw material, as well as to the extraction methods used, and the variety and origin of the plant. Therefore, the greatest amount of phenolic compounds from watercress leaves can be extracted with water and methanol, and this method could be used in products in the pharmaceutical and food industries due to their beneficial effects on health, especially the aqueous extract due to its zero toxicity.

Total flavonoids. The highest amount of flavonoids was found in the ethanolic extracts prepared by maceration with the rest for 7 d in the VW with a ratio of 1 : 10 and 1 : 15 w/v (Figure 3b). It is so because phenolic compounds, especially flavonoids, are more soluble in organic solvents such as ethanol (Rodríguez-Miranda et al. 2022). In the methanolic extracts with a 1 : 10 w/v ratio, no significant differences were found between GV and VW ($P > 0.05$) (Figure 3b). However, the aqueous extract obtained by infusion was more affected in the VW, since the content of total flavonoids decreased at both concentrations; the reason is that the boiling breaks the cell matrix, releasing bioactive compounds; however, when they are exposed to boiling for a long time, they tend to degrade. The impact of the rest time on the maceration was favoured by the methanol and ethanol solvents, since the longer the days of the rest, the greater amount of flavonoids was extracted, while with water and rest for 24 h, the content decreased mainly at the ratio of 1 : 10 w/v. This is due to the senescence of the leaves in which the chlo-

https://doi.org/10.17221/139/2023-CJFS

roplasts of plant cells are transformed into the gerontoplasts, and the degradation of chlorophyll producing carotenoids and flavonoids (characteristic of yellow-orange colours) occurs at the same time (Matile 2001; Krupinska 2006; Díaz-Mendoza et al. 2016). In addition, plant growth conditions, climatic conditions, soil types (nutrients) and the harvest period of raw materials can also be attributed to the extraction conditions of the above-mentioned compounds (Al-Snafi 2020; Pinela et al. 2020). The values found in this investigation are below those reported by Al-Snafi (2020): VW 2.881 mg quercetin equivalent (QE)·(100 g)$^{-1}$ and GW 3.977 mg QE·(100 g)$^{-1}$.

Antioxidant capacity

***ABTS*$^{+}$.** The results showed significant differences ($P < 0.05$) in all the extracts. The highest percentage of antiradical activity was at 1 : 15 w/v ratios in aqueous extracts (50.97–85.09% inhibition), followed by methanolic extracts (57.54–66.90% inhibition), with the highest antiradical activity in the extract from GW for 24 h (Figure 3c).

This is due to the type of compounds that watercress contains that are highly hydrophilic, such as flavonoids (quercetin-3-O-rutinoside, 7-O-glucoside, quercetin-3-O-triglucoside, kaempferol-3-O-(caffeoyldiglucoside)-7-O-rhamnoside, isorhamnetin) and catechin derivatives, followed by phenolic acids (caffeic acid, gallic acid, chlorogenic acid, ferulic acid, p-coumaric acid, p-hydroxybenzoic acid, sinapic acid, caftaric acid, vanillic acid, dicaffeoyltartaric acid, caffeoylmalic acid) and some glucosinolates [2-phenethyl glucosinolate (gluconasturtiin), glucosibarin, 4-methoxyglucobrassicin, glucobrassicin, 4-hydroxyglucobrassicin, glucohirsutin, glucotropaeolin and isothiocyanates] (Al-Snafi et al. 2020; Pinela et al. 2020).

These compounds present a large number of hydroxyl groups (-OH) in their chemical structures, responsible for granting this antioxidant capacity, due to the availability of donation of their hydrogen atoms to free radicals (Chaudhary et al. 2018). The amount of total phenols and flavonoids is not a determining factor of the antioxidant capacity of the extract, since, as can be seen in Figure 3c, the extracts prepared at a 1 : 10 w/v ratio that presented higher total phenols are the ones that are now below the antioxidant capacity of the extracts at a 1 : 15 w/v ratio.

***DPPH**.** In methanolic extracts of GW at the ratios of 1 : 10 and 1 : 15 w/v at times 0 h and 7 days, a higher percentage of inhibition was observed (Figure 3d). The lowest percentages were obtained with the ethanolic extracts with an inhibition range of 2.42–11.88%. This is because some phenolic compounds can react more quickly than others, such as quercetin and catechin, being more reactive than vanillic and p-coumaric acids (Oliveira et al. 2016). Therefore, the selection of the solvent for the extraction of active compounds is of great importance in complex food matrices, since it will determine the type of polyphenols that are extracted, while their amount also depends on polarity and solubility. The solubility of polyphenols increases with the addition of water because water weakens the hydrogen bonds of polyphenols with proteins (Safdar et al. 2017). That is why the results obtained in the antioxidant capacity by DPPH are low because the compounds extracted with water are mostly hydrophilic in nature, therefore these radicals react with lipophilic compounds (Ozdemir et al. 2024). While the ABTS+ radical acts on the compounds of hydrophilic and lipophilic nature, i.e. it can react with molecules that have a single hydroxyl group (Cerretani and Bendini 2010).

CONCLUSION

The watercress leaves in both stages of maturity showed important bioactive compounds, mainly phenols, flavonoids, phytosterols, and alkaloids. The aqueous extract of GW watercress leaves macerated for 24 h at a 1 : 15 w/v ratio had a higher antioxidant capacity, making this extract the most viable to be used as an alternative in food products. In addition, considering the extraction method and the type of solvent that makes it a viable and economical extraction method, it is recommended to carry out more research to protect the active compounds present in watercress, since they tend to be easily degraded by external factors such as light, pH, oxygen and temperature.

REFERENCES

Aires A., Carvalho R., Rosa E.A.S., Saavedra M.J. (2013): Phytochemical characterization and antioxidant properties of baby-leaf watercress produced under organic production system. CyTA-Journal of Food, 11: 343–351.

Al-Snafi A.E. (2020): A review on *Nasturtium officinale*: A potential medicinal plant. IOSR Journal of Pharmacy, 10: 33–43.

Almulaiky Y.Q., Aldhahri M., Al-abbasi F.A., Al-Harbi S.A., Shiboob M.H. (2020): *In vitro* assessment of antioxidant enzymes, phenolic contents and antioxidant capacity of the verdolaga (*Portulacaceae*). International Journal of Nutrition, 4: 36–47.

https://doi.org/10.17221/139/2023-CJFS

Ávila-Escalante M.L., Coop-Gamas F., Cervantes-Rodríguez M., Méndez-Iturbide D., Aranda-González I.I. (2020): The effect of diet on oxidative stress and metabolic diseases –Clinically controlled trials. Journal of Food Biochemistry, 44: e13191.

Boligon A.A., Janovik V.,Boligon A.A., Pivetta C.R., Pereira R.P., Rocha J.B.T.D., Athayde M.L. (2013): HPLC analysis of polyphenolic compounds and antioxidant activity in *Nasturtium officinale*. International Journal of Food Properties, 16: 61–69.

Cerretani L., Bendini A. (2010): Rapid assays to evaluate the antioxidant capacity of phenols in virgin olive oil. In: Preedy V.R., Watson R.R. (eds): Olives and Olive Oil in Health and Disease Prevention. Amsterdam. Elsevier, Academic Press: 625–635.

Chaudhary S., Hisham H., Mohamed D. (2018): A review on phytochemical and pharmacological potential of watercress plant. Asian Journal of Pharmaceutical and Clinical Research, 11: 102–107.

Chis M.S., Paucean A., Man S., Petrut G., Muresan A., Pop A., Pop C.R., Muste S. (2020): Watercress (*Nasturtium Officinale* R. Br.) chemical compositions and applications in food processing. Hoop and Medicinal Plants, 28: 59–68.

Díaz-Mendoza M., Velasco-Arroyo B., Santamaria M.E., González-Melendi P., Martinez M., Diaz I. (2016): Plant senescence and proteolysis: Two processes with one destiny. Genetics and Molecular Biology, 39: 329–338.

Engelen-Eigles G., Holden G., Cohen J.D., Gardner G. (2006): The effect of temperature, photoperiod, and light quality on gluconasturtiin concentration in watercress (*Nasturtium officinale* R. Br.). Journal of Agricultural and Food Chemistry, 54: 328–334.

Klimek-Szczykutowicz M., Szopa A., Ekiert H. (2018): Chemical composition, traditional and professional use in medicine, application in environmental protection, position in food and cosmetics industries, and biotechnological studies of *Nasturtium officinale* (watercress) – A review. Fitoterapia, 129: 283–292.

Krupinska K. (2006): Fate and activities of plastids during leaf senescence. In: Wise R.R., Hoober J.K. (eds.): The Structure and Function of Plastids. Dordrecht, Springer Netherlands: 433–449.

Larridon I., Villaverde T., Zuntini A.R., Pokorny L., Brewer G.E., Epitawalage N., Fairlie I., Hahn M., Kim J., Maguilla E., Maurín O., Xantos M., Hipp A.L., Forest F., Baker W.J. (2020): Tackling rapid radiations with targeted sequencing. Frontiers in Plant Science, 10: 1655.

Leon-Bejarano M., Ovando-Martínez M., Molina-Domínguez C.C., Trasviña-Mendoza R.A., Medina-Juárez L.Á. (2021): Identification and Antioxidant Activity of the Phenolic Compounds of *Jatropha cardiophylla* (Torr.) Müll. Arg. (Identificación y actividad antioxidante de los compuestos fenólicos de *Jatropha cardiophylla* (Torr.) Müll. Arg.) TIP Revista Especializada en Ciencias Químico-Biológicas, 24: 1–9. (in Spanish)

Maldonado-Santoyo M., Morales-López G. (2022): Chemical and nutritional Analysis in leaves of *Ricinus communis* (Análisis químico y nutricional en hojas de *Ricinus communis)*. Revista Cubana de Química, 34: 3–18. (in Spanish)

Matile P. (2001): Senescence and cell death in plant development: chloroplast senescence and its regulation. In: Aro E.M., Andersson B. (eds): Regulation of Photosynthesis. Dordrecht, Springer Academic Press: 277–297.

Mazandarani M., Momeji A., Zarghami M.P. (2013): Evaluation of phytochemical and antioxidant activities from different parts of *Nasturtium officinale* R. Br. in Mazandaran. Irian Journal of Plant Physiology, 3: 659–664.

Nattagh-Eshtivani E., Barghchi H., Pahlavani N., Barati M., Amiri Y., Fadel A., Khosravi M., Talebi S., Arzhang P., Ziaei R., Ghavami A. (2022): Biological and pharmacological effects and nutritional impact of phytosterols: A comprehensive review. Phytotherapy Research, 36: 299–322.

Núñez D., Balboa N., Quilaqueo N., Alvear M., Paredes M. (2018): Evaluation of the immunomodulatory activity of methanolic extracts and alkaloids of *Berberis darwinii* H. (Berberidaceae)[Evaluación de la actividad inmunomoduladora de extractos metanólicos y de alcaloides de *Berberis darwinii* H. (Berberidaceae)]. International Journal of Morphology, 36: 454–459. (in Spanish)

Oliveira G.K.F., Tormin T.F., Sousa R.M.F., de Oliveira A., de Morais S.A.L., Richter E.M., Munoz R.A.A. (2016): Batch-injection analysis with amperometric detection of the DPPH radical for evaluation of antioxidant capacity. Food Chemistry, 192: 691–697.

Ozdemir M., Gungor V., Melikoglu M., Aydiner C. (2024): Solvent selection and effect of extraction conditions on ultrasound-assisted extraction of phenolic compounds from galangal (*Alpinia officinarum*). Journal of Applied Research on Medicinal and Aromatic Plants, 38: 100525.

Paladino S.C., Zuritz C.A. (2011): Antioxidant grape seed (*Vitis vinifera* L.) extracts

efficiency of different solvents on the extraction process [Extracto de semillas de vid (*Vitis vinifera* L.) con actividad antioxidante: Eficiencia de diferentes solventes en el proceso de extracción]. Revista de la Facultad de Ciencias Agrarias, 43: 187–199. (in Spanish)

Pereira C., Barros L., Carvalho A.M., Ferreira I.C.F.R. (2011): Nutritional composition and bioactive properties of commonly consumed wild greens: Potential sources for new trends in modern diets. Food Research International, 44: 2634–2640.

https://doi.org/10.17221/139/2023-CJFS

Pinela J., Carvalho A.M., Ferreira I.C.F.R. (2020): Watercress. In: Jaiswal A.K. (ed.): Nutritional Composition and Antioxidant Properties of Fruits and Vegetables. London, United Kingdom. Elsevier, Academic Press: 197–219.

Rodríguez-Miranda J., Carlos-Isidro A., Martínez-Sánchez C.H., Herman-Lara E., Torruco-Uco J.G., Santiago-Adame R., Hernández-Santos B. (2022): Phytochemical screening, polyphenols content and antioxidant activity of by-products of two corn variety. Emirates Journal of Food and Agriculture, 35: 806–814.

Safdar M.N., Kausar T., Jabbar S., Mumtaz A., Ahad K., Saddozai A.A. (2017). Extraction and quantification of polyphenols from kinnow (*Citrus reticulate* L.) peel using ultrasound and maceration techniques. Journal of Food and Drug Analysis, 25: 488–500.

Sánchez-Chino, X. M., Ruíz-Ruíz, J. C., Salazar-Vega, M., Méndez-Flores, O., & Olivo-Vidal, Z. E. (2019): Phenolic compounds and anti-inflammatory activity in vitro, of Tradescantia zebrina extracts (Compuestos fenólicos y actividad antiinflamatoria in vitro, de extractos de Tradescantia zebrina). En J. M. Herrera & C. H. Hernández (Eds.), Investigaciones científicas y tecnológicas para la seguridad alimentaria (pp. 451–457). (in Spanish)

Xu Z.Y., Xi Y.F., Zhou W.Y., Lou L.L., Wang X.B., Huang X.X., Song, S.J. (2020): Alkaloids and monoterpenes from the leaves of *Isatis tinctoria* Linnaeus and their chemotaxonomic significance. Biochemical Systematics and Ecology, 92: 104089.

Zhang Z., Li X., Sang S., McClements D.J., Chen L., Long J., Jiao A., Jin Z., Qiu C. (2022): Polyphenols as plant-based nutraceuticals: Health effects, encapsulation, nano-delivery, and application. Foods, 11: 2189.

Received: August 23, 2023
Accepted: May 29, 2025
Published online: August 26, 2025