

Influence of drying temperature on the organoleptic properties, antioxidant activity and polyphenol content in dried leaves of *Allium ursinum* L. subsp. *ucrainicum*

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Abstract

Keywords:

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Introduction. The short vegetative occurrence of *Allium ursinum* limits its availability. Therefore, drying seems to be an excellent method for year-round preservation. The aim of the present study was to determine the influence of drying temperature on antioxidant activity and polyphenol content in dried leaves of *Allium ursinum* L. subsp. *ucrainicum* and their organoleptic properties.

Materials and methods. The effect of three drying temperatures (40, 50 and 60 °C) on the organoleptic properties (colour, dehydration and rehydration ability), antioxidant activity and polyphenol content in the dried leaves of *A. ursinum* was evaluated. The colour of the samples was measured using the computer vision system. The total phenolic content was determined spectrophotometrically and the antioxidant activity was determined using the 2,2-diphenyl-1-picrylhydrazyl method.

Results and discussion. Significant differences were found between the fresh, dehydrated and rehydrated *A. ursinum* samples for all the colour parameters analysed (dried leaves showed a much lower intensity of green colour than fresh). Drying at higher temperature results in greater colour change, which is more pronounced at higher drying temperatures (60 °C) due to chlorophyll degradation. The drying temperatures had a statistically significant effect on the dehydration and rehydration capacity of the dried samples. The higher drying temperature resulted in the higher degree of dehydration and rehydration (the pores of the dried food allowed water to re-enter the cells). Convection air-drying resulted in considerable moisture removal from the fresh leaves of *A. ursinum* (more than 91%), but the organoleptic quality of the *A. ursinum* leaves was maintained. The drying conditions tested had a significant effect on the total phenolic content and antioxidant activity of *A. ursinum* leaves. An increase of temperature drying decreased the total polyphenol content in the dried *A. ursinum* leaves. Across the range of measurements, the samples dried at lower temperatures had the higher antioxidant capacity, while the higher drying temperatures resulted in a greater decrease in the antioxidant activity of the dried plant material. *A. ursinum* is considered one of the functional foods for human consumption due to its high nutritional value and prophylactic or therapeutic effects in various diseases. To obtain a high quality dried product, the drying process should ensure a quality comparable to fresh vegetables.

Conclusions. Air drying showed a significant effect on the colour, drying properties, total polyphenol content and antioxidant activity of the leaves of *A. ursinum*. The losses were significantly dependent on the drying temperature and were more pronounced at higher process temperatures.

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Introduction

Allium ursinum L. is known by many different names: wild garlic, leek, wood garlic, bear's garlic, ramsons, buckrams, broad-leaved garlic, gypsy onion and pig's garlic. It belongs to the large family *Amaryllidaceae*, which is represented all over the world with 59 genera and over 850 species. As a member of the genus *Allium*, wild garlic is closely related to herbs such as onion (*Allium cepa*), garlic (*Allium sativum*), leek (*Allium ampeloprasum*), and chives (*Allium schoenoprasum*) (Hanen et al., 2012). *Allium* species are considered a source of phytonutrients with diverse biological activities (Lachowicz et al., 2017; Gitin et al., 2012), such as antibacterial, antifungal (Parvu et al., 2011), antioxidant (Bozin et al., 2008), and therapeutic activities, which are associated with the presence of sulfur components (Godevac et al., 2008). Due to the presence of sulfur compounds, which are otherwise rather characteristic components of *Allium* plants, *A. ursinum* has a distinctive garlic-like odour.

A. ursinum is a plant with a high potential for the prevention and treatment of cardiovascular, respiratory and digestive problems, as well as for the sterilisation of wounds (Sobolewska et al., 2013) and the prevention of carcinogenic diseases (Sengupta et al., 2004). These properties are due to many substances, including cysteine sulfoxides and thiosulfates, ajoenes and dithiines, phenolic compounds, saponins and vitamins C, E and A (Lu et al., 2011; Roldan- Marin et al., 2009).

It grows mainly in moist deciduous forests throughout Europe and in parts of Asia and North Africa (Oborny et al., 2011; Rola 2012). *Allium ursinum* L. comprises two subspecies *Allium ursinum* subsp. *ursinum* and *Allium ursinum* subsp. *ucrainicum*. In Eastern and South Eastern Europe, and Croatia as well, *Allium ursinum* subsp. *ucrainicum* grows in continental and mountainous areas (Rola, 2012; Tutin 1957). Although all parts of this plant are edible (bulbs, leaves, buds, flower stalks, flowers and immature green cobs), leaves and bulbs are generally preferred for consumption. The fresh leaves or dried herb of *A. ursinum* is used in local cuisines of Europe. There are many products derived from garlic as a raw material: garlic powder, paste, extract, oil, macerated garlic, pickled garlic, dried garlic. The medicinal parts of the plant are the young spring leaves, harvested in April and May, and the underground bulbs, collected in the summer and autumn months. However, the short vegetative presence of *A. ursinum* limits its availability, so drying can be a solution for preserving it throughout the year.

Since agricultural products are highly seasonal and therefore abundant at certain times of the year, preserving fruits and vegetables through drying can both avoid major waste and ensure availability in the off-season. Drying is one of the thermal processes that agricultural products undergo in the post-harvest phase. The aim is to reduce the moisture content of the product in order to delay adverse biological (prevents the growth of microorganisms), chemical and enzymatic processes. Although drying is an alternative to extend the shelf life of food, it is a fact that the quality of dehydrated food is usually lower than that of the original food. Therefore, it is of interest to minimise chemical changes such as enzymatic and non-enzymatic browning and to maximise the retention of nutrients such as macronutrients (proteins, sugars, fibres), micronutrients (vitamins, minerals) or bioactive compounds (phenolic compounds, carotenoids, isoflavones) during drying. The drying process is considered to affect the content, activity and bioavailability of bioactive compounds (mainly polyphenols) in *A. ursinum* leaves. Therefore, the evaluation of the effects of drying on the naturally occurring antioxidants is a key issue in the choice of technological conditions that allow the preservation of their original activity and bioavailability. A lot of recent work has focused on studying the effects of drying on the phenolic compound content and antioxidant activities of dried vegetables (Kim et al., 2013; Ozgur et al., 2011; Sahoo et al., 2015; Telfser

et al., 2019). To achieve better results in terms of dried product quality, researchers have worked on optimising drying methods and different drying conditions (Arslan et al., 2010; Lim et al., 2007; Roshanak et al., 2015). The major quality problems associated with drying are loss of flavour (Ozkan-Karabaca et al., 2018), discolouration (Guine et al., 2012) and poor rehydration properties of the dried product (Aravindakshan et al., 2021; Lewicki, 1998).

The aim of the present study was to determine the influence of drying temperature on antioxidant activity and polyphenol content in dried leaves of *Allium ursinum* L. subsp. *ucrainicum* and their organoleptic properties.

Materials and methods

Materials

The plant material (fresh leaves) used in this study was collected from a natural population of wild garlic, *Allium ursinum* L. subsp. *ucrainicum*, before flowering (April 2021) in the Papuk Geopark (45°32'N 17°39'E) in the Slavonia region, Croatia. All plant samples were free from external damage and hand-picked. The leaves of *A. ursinum* were packed in linen bags and kept in the refrigerator for 24 hours until the start of the analysis of the plant material.

Drying

Drying was carried out in a drying cabinet with hot air, in which the fresh leaves of *A. ursinum* were placed in a thin layer on perforated stainless steel trays. The drying cabinet were equipped with a fan, a speed controller, a temperature controller, heating elements, a humidity, temperature, and air velocity meter. Fresh samples were dried at different drying temperatures of 40 °C, 50 °C, and 60 °C with a constant air velocity of 1.5 m/s and relative humidity of 35-45%. The drying process started when the drying conditions were reached. Weight loss was performed at a fixed time interval, and drying continued until a moisture content of approximately 12% (wet basis) was reached. Three independent dryings were performed for each drying temperature. The effect of temperatures on the quality of dried leaves of *A. ursinum* was determined by the colour characteristics, dehydration and rehydration capabilities phenolic compounds, and antioxidant properties.

Determination of physicochemical characteristics

Dry matter content, ash, crude fat, pH and total acidity were determined in fresh *A. ursinum* samples. The analysis was performed in accordance with Association of Official Analytical Chemists standards (AOAC, 2000). The dry matter content of the leaves was determined by drying 5.0 g of the samples at 105 °C until constant weight. Ash content was determined by burning 5.0 g of the fresh samples at 550-600 °C until a homogeneous white ash without black spots was obtained. Crude fat was obtained by exhaustive extraction of 10.0 g of each sample in a Soxhlet apparatus using petroleum ether (boiling range 40-60 °C) as solvent (Dini et al., 2008). Titratable acidity was determined by potentiometric titration and pH by a digital pH meter (Mettler Toledo, FiveEasy FE20, Switzerland).

Colour measurement

The colour of the fresh, dehydrated, and rehydrated leaves of *A. ursinum* samples was measured using the computer vision system. Samples were ground in a grinder (Retsh, Grindomix GM 200, Düsseldorf, Germany) to obtain a fine powder (Figure 1). For each sample (fresh, dehydrated, and rehydrated), colour parameters were measured three times directly on the product using a 2.2-megapixel digital SLR camera (EOS 1100D, Canon Ltd., Japan), calibrated with a calibration plate (Datacolor SpyderCheckr™, New Jersey, USA) just before imaging. The 24-bit colour images were captured in TIFF format and in the *RGB* colour model. Samples were photographed in a photochamber illuminated by four LED lamps with a diffuser.

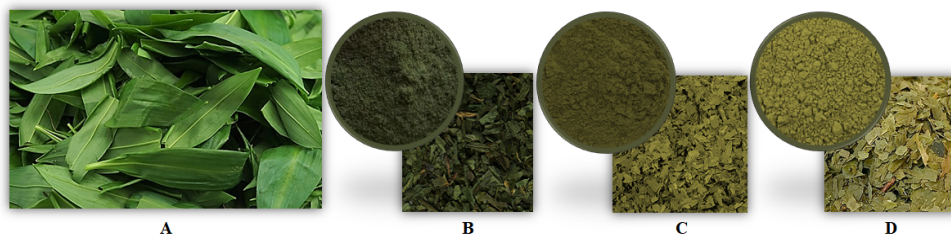


Figure 1. Appearance of fresh (A) and dehydrated *A. ursinum* leaves at 40 °C (B), 50 °C (C), and 60 °C (D)

The colour parameters of the samples was determined using ImageJ™ image processing software (Wayne Rasband, National Institute of Health, Maryland, USA). The results were expressed as values for red (*R*), green (*G*), and blue (*B*) in the *RGB* colour system. The obtained colour values were then converted (Viscarra Rossel et al., 2006) and presented in the *CIELAB* and $L^*C^*h^\circ$ colour system (Westland, 2016; Zhang et al., 2003), which is commonly used to evaluate dried foods. The three parameters L^* (lightness, from black $L^* = 0$ to white $L^* = 100$), a^* (a negative value of a^* represents green, while a positive value represents red colour) and b^* (a positive b^* represents yellow and a negative represents blue colour) were used for further calculation of hue angle, colour saturation, and total colour difference.

Hue angle (h°) is the attribute by which a colour is identified as green, yellow, red, etc. An angle of 0° or 360° represents red hue, whilst angles of 90° , 180° and 270° represent yellow, green and blue hues, respectively (Maskan, 2001). Hue angle is used to define the difference of a certain colour with reference to grey colour with the same lightness:

$$h^\circ = \tan^{-1} \left(\frac{b^*}{a^*} \right)$$

Colour saturation or chroma (C^*), considered the quantitative attribute of colourfulness. The higher the chroma values, the higher is the colour intensity of samples perceived by humans. Chroma were calculated from the values of a^* and b^* (Lopez Camelo et al., 2004):

$$C^* = \sqrt{a^{*2} + b^{*2}}$$

Total colour difference (ΔE_{ab}) is colour change represents by distance vector between the initial colour values (fresh samples) and the dehydrated/rehydrated colour coordinates (Roy Choudhury, 2015). Total colour difference were calculates as follows:

$$\Delta E_{ab} = \sqrt{(L_0^* - L^*)^2 + (a_0^* - a^*)^2 + (b_0^* - b^*)^2}$$

where L_0^* , a_0^* and b_0^* are the colour parameters of fresh leaves of *A. ursinum* samples, and L^* , a^* , and b^* are dehydrated/rehydrated colour parameters.

Drying characteristics

The quality index of a dried product were observed and in this terms following parameters was calculated: dehydration ratio (*DR*), and rehydration ratio (*RR*). The *DR* is important parameter to show the bulk reduction in the weight of dried sample (higher the *DR*, better the quality of drying process). The *RR* is quality index for all dried product and higher the *RR*, better the quality of product. Dehydration ratio was calculated by taking the weights of sample before drying in gram (m_B) and weights of sample after drying in gram (m_D) (Kaur et al., 2008):

$$DR = \frac{m_B}{m_D}$$

To express ability of the dried material to absorb water the *RR* was used, and estimated according to method of Ranganna (2004). Approximately 5 g of dried samples of *A. ursinum* were placed in a 100 ml distilled water and bring to boil within 3 min. After 5 min of mild boiling, the mixture was cooled and then filtered under vacuum and weighed (mass of drained weight). Rehydration ratio was calculated by taking the drained weight (g) of rehydrated sample (m_R), and the weight (g) of dry sample used for rehydration (m_D) (Lewicki, 1998):

$$RR = \frac{m_R}{m_D}$$

Sample extract preparation

The extract from the leaves of *A. ursinum* was obtained by adding 2.5 g of fresh or dried leaf powder to 25 mL of absolute methanol and stirring with a magnetic stirrer for 30 minutes. The resulting mixture was stored in the dark at 4 °C for 24 hours and then filtered. The resulting extract was stored at 4 °C until further analysis (Dewanto et al., 2002).

Determination of total phenolic content

The total phenolic content (*TPC*) was determined spectrophotometrically according to the method Singleton et al. (1965) with gallic acid as standard. The 0.3 mL of the extract sample was mixed with diluted (1:10) Folin reagent (1.5 mL) and mixed vigorously for three min. Then 6.0% sodium carbonate solution (1.5 mL) was added and shaken. After standing for 90 minutes in dark at room temperature, the absorbance was measured at 760 nm using a UV-VIS spectrophotometer (Shimadzu, UV-1280, Germany). *TPC* of fresh and dried leaves was expressed using the calibration curve with gallic acid (0–500 µg/mL) as grammes of gallic acid equivalents (GAE) per 100 gramme of dry matter (g GAE /100 g d.b.).

Determination of antioxidant activity

Antioxidant activity (*AOA*) of the extracts was measured according the Brand-Williams et al. (1995) method based on using 2,2-diphenyl-1-picrylhydrazyl (DPPH). The reaction mixture was prepared using 0.1 mL of extract and 3.9 mL of DPPH methanol solution (0.1 mM). The mixture was shaken, left in the dark for 30 min, and absorbance was measured using the UV – VIS spectrophotometer (Shimadzu, UV-1280, Germany) at 517 nm. The *AOA* was expressed as the percentage inhibition of the DPPH radical.

Statistical analysis

Each drying test was performed in triplicate and all analyses were performed in at least five replicates, unless otherwise stated in a specific analysis. One-way analysis of variance (ANOVA) and multiple comparison post-hoc Fisher LSD (least significant-difference) test were used to evaluate the significant difference of the data at $p < 0.05$. Data were expressed as means ± standard deviation. Statistica 14 from StatSoft was used for statistical analysis.

Results and discussion

Determination of physicochemical characteristics

The results of the physicochemical properties of the leaves of *A. ursinum* are shown in Table 1. It can be seen that the average values of dry matter, crude fat content, total acidity and pH in the fresh leaf samples are 9.42, 8.84, 3.72, 0.90 and 5.50, respectively, and are in agreement with the results of other studies (Blazewicz-Wozniak et al., 2011; Dyduch et al., 2019).

Table 1

Physicochemical characteristics of fresh leaves of *A. ursinum* L.

Dry matter, %	Ash content, %	Crude fat content, %	Titrateable acidity, g acid/100 g plant d.b.	pH
9.42±0.48	8.84±0.52	3.72±0.29	0.90±0.03	5.50±0.09

Results are expressed as mean ± standard deviation.

Colour degradation

Product colour is an important quality parameter that must be maintained during drying. The leaves of the *A. ursinum* samples were dried at 40, 50, and 60 °C to the desired moisture content. The colour of the samples was measured before (fresh) and after drying (dehydrated and rehydrated). The effect of the different air temperatures on the colour characteristics of the *A. ursinum* samples is shown in Figures 2–7.

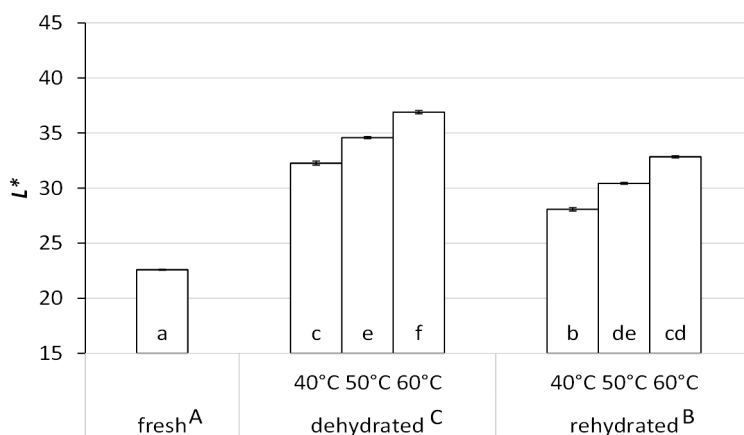


Figure 2. Effect of drying air temperature on lightness (L^*) of fresh, dehydrated and rehydrated *A. ursinum* leaves

The data are presented as the mean ± standard deviation. Bars with different letters are significantly different ($p < 0.05$)

The colour of the leaves of *A. ursinum* was characterised by higher colour parameters L^* , a^* , and b^* of the dried plant material compared to fresh leaves. The value of hue angle (h°) was lower in the dried material than in the raw or rehydrated material. Significant differences were observed in all analysed colour parameters between the fresh, dehydrated, and rehydrated leaves of *A. ursinum* dried at different air temperatures. Adverse changes in the colour of *A. ursinum* leaves are mainly due to the degradation of chlorophyll contained in them. Chlorophyll content decreases with increasing temperature, process duration (Lin et al., 2010; Krokida et al., 1998), and the presence of oxygen, leading to oxidation of the unsaturated colour compounds contained in the material (Negi et al., 2001), which contributes to unfavourable changes in the colour determinants of the dried material. Heating at higher temperatures caused the colour of *A. ursinum* leaves to change from green to olive brown, which is attributed to pheophytinization (Nido et al., 2003; Martins et al., 2002).

Figure 2 shows that the lightness (L^*) ranged from 22.59 ± 0.06 to 36.89 ± 0.14 regardless of drying temperature, with the lowest L^* values obtained for fresh samples (22.59 ± 0.06) and the highest for samples dried at 60°C (36.89 ± 0.14). The drying temperature had a significant effect on the L^* values of the dehydrated and rehydrated samples. The L^* values increased proportionally with the drying temperature. The L^* values for the rehydrated samples were lower compared to the dehydrated samples. Rudy et al. (2020) also reported decrease in L^* values after convection drying. A negative a^* value represents a green colour, while a positive value represents a red colour.

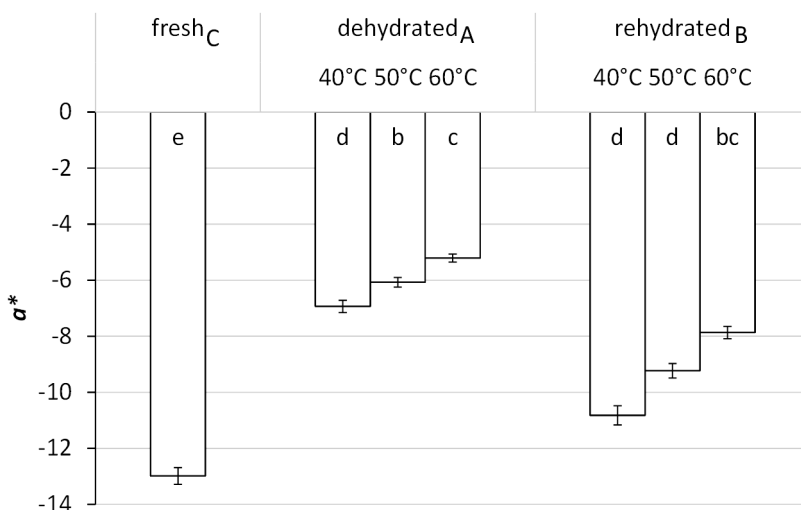


Figure 3. Effect of drying air temperature on colour parameter a^* (redness – greenness) of fresh, dehydrated and rehydrated *A. ursinum* leaves

The data are presented as the mean $\pm$ standard deviation. Bars with different letters are significantly different ($p < 0.05$)

The results of chromatic component redness – greenness (a^*) of *A. ursinum* leaves are presented in Figure 3 where can it be seen that a^* values ranged from -12.99 ± 0.30 to -5.21 ± 0.14 regardless of drying temperature, with the lowest a^* values obtained for fresh samples (-12.99 ± 0.30) and the highest (-5.21 ± 0.14) for samples dried at 60°C . The green colour is dominant in all samples, although the green hue is more pronounced in fresh and rehydrated samples. The drying temperature had a significant effect on the a^* values of the

dehydrated and rehydrated samples, and the a^* values for the dehydrated samples were lower compared to the rehydrated samples processed at the same temperature. Thus, the dehydrated leaves showed a much lower intensity of green colour than the fresh leaves. This effect is more pronounced at higher drying temperatures (60 °C) due to chlorophyll degradation (Guine et al., 2012).

The results of chromatic component yellowness – blueness (b^*) of *A. ursinum* leaves are presented in Figure 4 where can it be seen that b^* values ranged from 14.78 ± 0.19 to 21.10 ± 0.13 regardless of drying temperature, with the lowest b^* values obtained for fresh samples (14.78 ± 0.19) and the highest for dehydrated samples (21.10 ± 0.13) dried at 60 °C. The positive b^* value, representing the yellow colour, increases significantly after drying and rehydration. Arslan et al., (2010) reported similar results. There were statistical differences between dehydrated and rehydrated samples. The b^* values for the rehydrated samples were smaller compared to the dehydrated samples processed at the same temperature.

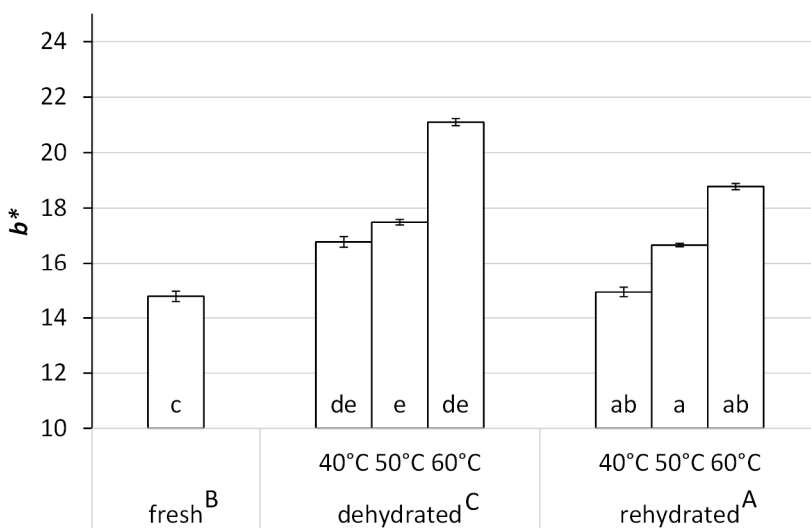


Figure 4. Effect of drying air temperature on colour parameter b^* (yellowness – blueness) of fresh, dehydrated and rehydrated *A. ursinum* leaves

The data are presented as the mean $\pm$ standard deviation. Bars with different letters are significantly different ($p < 0.05$)

The hue angle (h°) values ranged from 103.87 ± 0.31 to 131.30 ± 0.99 regardless of drying temperature (Figure 5), with the lowest h° values obtained for the samples dried at 60 °C (103.87 ± 0.31) and the highest for the fresh samples (125.10 ± 0.13). The dried leaves of *A. ursinum* had lower h° values than the raw material. There were statistical differences between dehydrated and rehydrated samples, with drying resulting in a significant decrease in h° values of the dried material. The h° values of the dehydrated samples were smaller compared to the rehydrated samples processed at the same temperature. The hue angle of the dehydrated sample decreased with increasing heating temperature. The decrease in hue angle corresponds to a decrease in the intensity of the green and an increase in the yellow colour. The decrease in hue angle in this study is consistent with the results reported by Lau et al., (2000) that prolonged heating of green vegetables leads to deterioration of chlorophyll pigments and a change in colour from green to olive green.

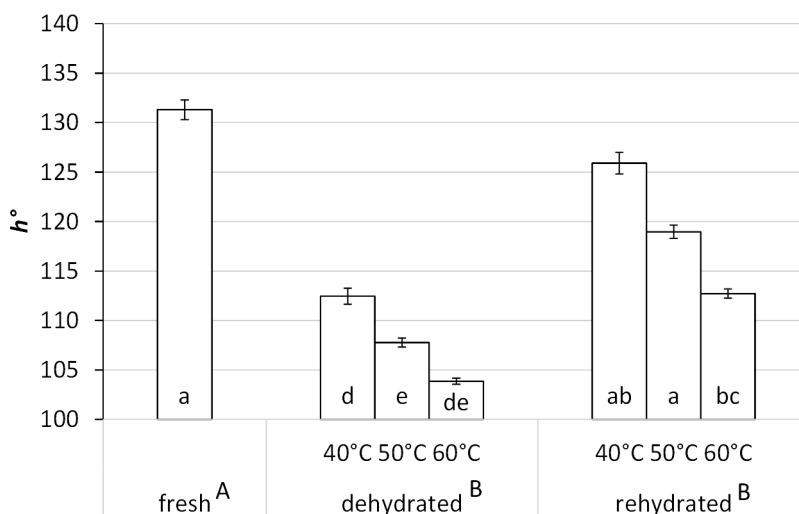


Figure 5. Effect of drying air temperature on hue angle (h°) of fresh, dehydrated and rehydrated *A. ursinum* leaves

The data are presented as the mean $\pm$ standard deviation. Bars with different letters are significantly different ($p < 0.05$)

The results of colour saturation (C^*) of *A. ursinum* leaves are presented in Figure 6. It can be seen that C^* ranged from 18.12 ± 0.18 to 21.72 ± 0.15 regardless of drying temperature, with the lowest C^* values obtained for dehydrated samples dried at 40 °C (18.12 ± 0.18) and the highest at 60 °C (21.72 ± 0.15). Increasing the temperature of the drying air resulted in an increase in colour saturation during drying. There were no statistical differences between dehydrated and rehydrated samples. The C^* values for the rehydrated samples were smaller compared to the dehydrated samples processed at the same temperature.

Total colour difference (ΔE_{ab}) is a colorimetric parameter used to estimate the colour change of food during processing. Figure 7 shows that ΔE_{ab} values ranged from 5.91 ± 0.10 to 17.47 ± 0.19 regardless of drying temperature, with the lowest ΔE_{ab} values obtained for rehydrated samples dried at 40 °C (11.60 ± 0.01) and the highest for dehydrated samples dried at 60 °C (17.47 ± 0.19). There were statistical differences between dehydrated and rehydrated samples. The ΔE_{ab} values for the rehydrated samples were smaller compared to the dehydrated samples processed at the same temperature. It is evident that drying at higher temperature results in greater colour change (Kumar et al., 2004).

Total colour difference (ΔE_{ab}) is a colorimetric parameter used to estimate the colour change of food during processing. Figure 7 shows that ΔE_{ab} values ranged from 5.91 ± 0.10 to 17.47 ± 0.19 regardless of drying temperature, with the lowest ΔE_{ab} values obtained for rehydrated samples dried at 40 °C (11.60 ± 0.01) and the highest for dehydrated samples dried at 60 °C (17.47 ± 0.19). There were statistical differences between dehydrated and rehydrated samples. The ΔE_{ab} values for the rehydrated samples were smaller compared to the dehydrated samples processed at the same temperature. It is evident that drying at higher temperature results in greater colour change (Kumar et al., 2004).

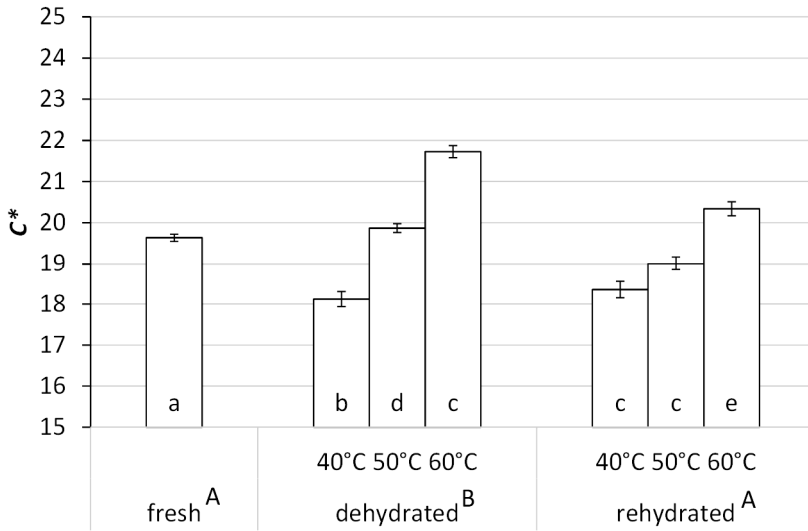


Figure 6. Effect of drying air temperature on chroma (C^*) of fresh, dehydrated and rehydrated *A. ursinum* leaves
 (The data are presented as the mean $\pm$ standard deviation. Bars with different letters are significantly different ($p < 0.05$))

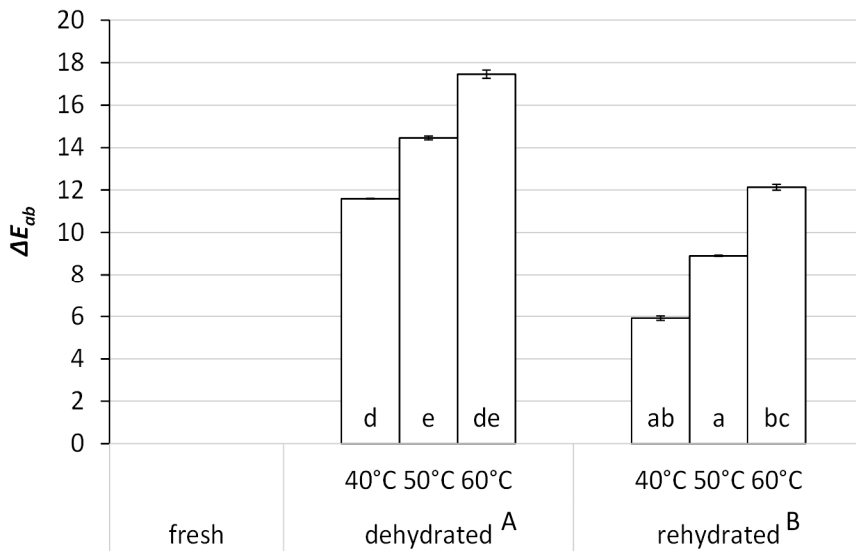


Figure 7. Effect of drying air temperature on colour difference (ΔE_{ab}) of fresh, dehydrated and rehydrated *A. ursinum* leaves
 The data are presented as the mean $\pm$ standard deviation. Bars with different letters are significantly different ($p < 0.05$)

Dehydration and rehydration ability

The rehydration properties of a dry product are often used as an indicator of the quality of a dry product. Rehydration is a complex process that is influenced by both the physical and chemical changes associated with drying and the treatments that precede dehydration. Figure 8 shows the degree of dehydration and rehydration of *A. ursinum* leaves depending on the different temperatures of the drying air of the samples.

The dehydration ratio (*DR*) indicates the weight loss of the dried product, with high values indicating a better drying process. The values of *DR* at different drying air temperatures are shown in Figure 8. The values of *DR* differed significantly between the different drying air temperatures. It varies between 5.45 ± 0.184 and 6.65 ± 0.041 and increases with increasing drying air temperature from 40 to 60 °C.

Rehydration is a method of analysing dried products. The rehydration ratio (*RR*) indicates the physical and chemical changes during drying, which are influenced by the processing conditions and the composition of the samples. The *RR* values (Figure 8) differed significantly between the different drying air temperatures and ranged from 4.09 ± 0.083 to 6.20 ± 0.104 . It was found that the *RR* of the samples dried at higher temperatures gave the highest rehydration. A high *RR* value means that the dried product is of good quality as the pores allow water to re-enter the cells.

Drying temperatures had a statistically significant effect on the dehydration and rehydration capacity of the dried *A. ursinum* leaves. The higher the drying temperature, the higher the degree of dehydration and rehydration of the *A. ursinum* leaves. Sahoo et al. (2015) and Ozgur et al. (2011) made similar observations. The drying process leads to changes in the permeability of the cell walls, loss of osmotic pressure and migration of solutes, which affects the rehydration ratio (Sharma et al., 2005). The less elastic cell walls and the reduced water binding capacity of proteins and starch reduce the rehydration ratio of the products, but this phenomenon is significantly reduced by optimising the drying process and the negative factors associated with cell rehydration are reduced (Kumar et al., 2004).

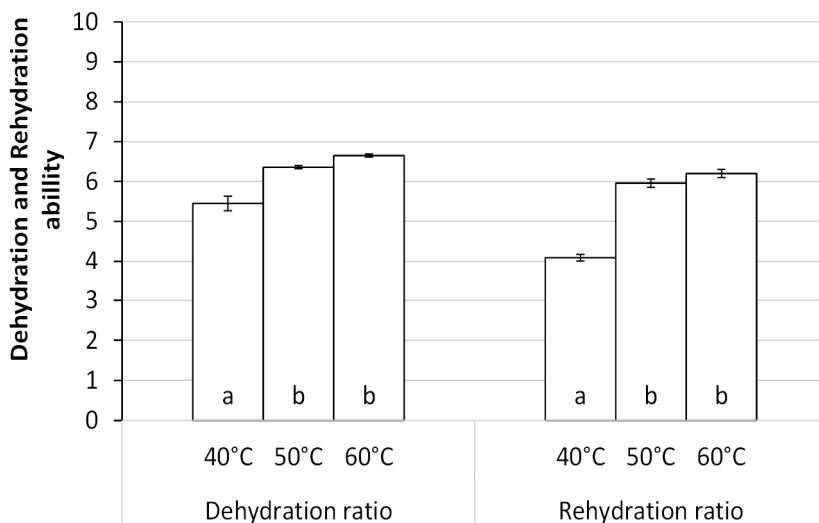


Figure 8. Effect of drying temperature on dehydration (*DR*) and rehydration (*RR*) ratio of dried leaves of *Allium ursinum*.

The data are presented as the mean $\pm$ standard deviation. Bars with different letters are significantly different ($p < 0.05$)

Total phenolic content and antioxidant activity of *A. ursinum*

Drying is one of the oldest techniques for preserving food for later use. In this technique, water is removed to reduce water activity, which reduces bacterial activity in the dried food. In addition to the safety of food during preservation, many researchers have focused on the changes in phytochemicals during drying or dehydration. The degradation of phenolic compounds is mainly caused by oxidation, cleavage of covalent bonds or enhanced oxidation reactions due to thermal processing (Nicoli et al., 1999). Phytochemicals such as phenolic acid and flavonoids, which occur in fruits, vegetables and cereals in free and bound forms, are degraded or change their structural form during thermal and non-thermal processing. As processing progresses, naturally occurring antioxidants are degraded and new compounds with potential antioxidant activity are formed. Food processing involves heating with various energy transfer media such as water, air, oil and electromagnetic waves. Food processing involves various transformations of phenols that produce yellowish or brownish pigments (Clifford, 2000). The most important phenols in onions are quercetin, gallic acid, ferulic acid and their glycosides (Nitta et. al, 2007). Total phenolic content (TPC) was assessed in both fresh and dried leaves to compare the effects of different drying conditions on the change in TPC. The results are shown in Figure 9.

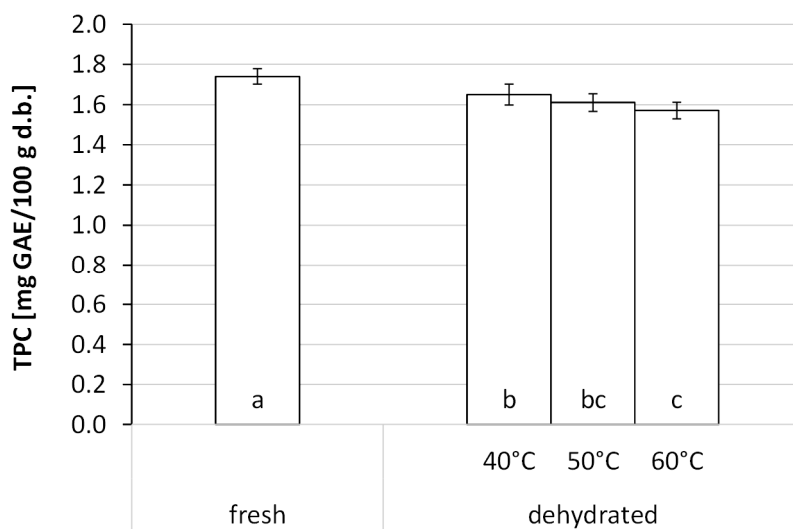


Figure 9. Total phenolic content of dried leaves of *Allium ursinum*.

The data are presented as the mean ± standard deviation. Bars with different letters are significantly different ($p < 0.05$)

The dried material of *A. ursinum* leaves obtained by convection drying was characterised by a decrease in TPC, which could be due to the degradation of phenolic compounds by drying (Lim et al., 2007). The TPC of the samples studied varied from 1.57 ± 0.041 to 1.74 ± 0.038 g GAE / 100 g dry weight. The highest contents of total polyphenols were found in the fresh samples and the lowest polyphenol contents in the samples dried at 60 °C. The dried material obtained after different drying air temperatures (40, 50 or 60 °C) differed

significantly in *TPC* content. Furthermore, the loss of this component was significantly different in the dried material compared to the raw material. The *TPC* content was lower at 60 °C than at the other two drying temperatures. The increase in drying air temperature during convection drying contributed to a decrease in *TPC* in the dried *A. ursinum* leaves. Physical and biological factors such as temperature increase and enzymatic activity can lead to the destruction of phenolic antioxidants such as phenolic acids and anthocyanins. According to Korus (2011), hot drying air promotes the oxidation of polyphenols by the oxygen absorbed by the convection drying air. The loss of polyphenol content is also attributed to their use as reactants in the Maillard reaction (Nicoli et al., 1999). Martin-Cabrejas et al. (2009) have reported that the reduction in *TPC* content could also be due to the binding of polyphenols to other compounds or to changes in their chemical structure after heat treatment. These changes prevent their extraction and determination with the methods used.

From the results of the antioxidant activity (*AOA*) of the dried plant material, it can be concluded that convection drying has an influence on the reduction of *AOA* (Figure 10). Drying of *A. ursinum* leaves resulted in a decrease in *AOA* of the dried material, regardless of the drying temperature used, compared to the raw plant material (88.4%). Across the range of measurements, the samples dried at lower temperatures had the higher value of *AOA*, while the higher drying temperatures resulted in a greater decrease in the antioxidant potential of the dried plant material (53.3, 45.3 and 40.7% at drying temperatures of 40, 50 and 60 °C, respectively).

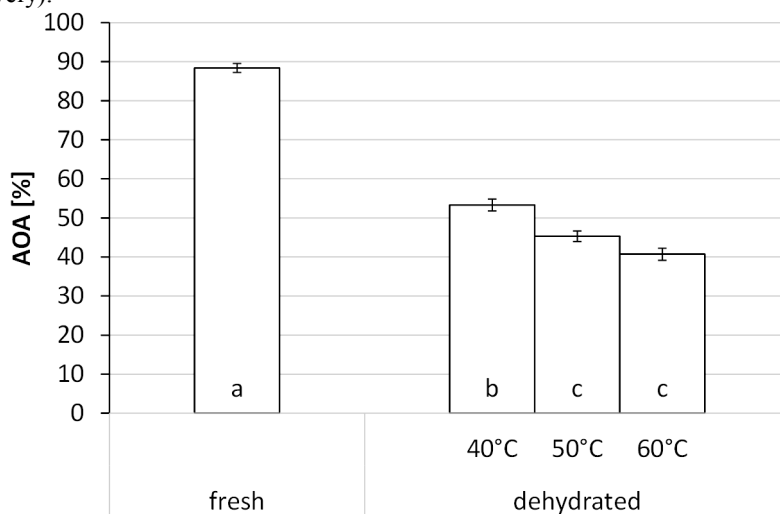


Figure 10. The antioxidant activity of leaves of *Allium ursinum*.

The data are presented as the mean $\pm$ standard deviation. Bars with different letters are significantly different ($p < 0.05$)

Antioxidant phytochemicals in plants can be broadly classified as carotenoids, phenols, alkaloids, nitrogenous compounds and organosulphur compounds (Liu, 2004). Antioxidant activity correlates with the presence of phytochemicals such as phenols, flavonoids and anthocyanins in food (Sun et al., 2002). Therefore, evaluating food processing operations that affect antioxidant activity in processed foods is critical to optimising conditions to increase or maintain their availability and functionality. Some authors report that antioxidant activity

increases or is maintained in processed foods, which may be due to the development of new compounds with potential antioxidant capacity, although the content of naturally occurring antioxidants has decreased significantly due to heat treatment. (Anese et al., 1999; Nicoli et al., 1997; 1999).

Conclusion

1. The colour of the samples was measured using a non-destructive method on fresh, dehydrated and rehydrated plant material, and significant differences were found in all the colour parameters analysed. It is evident that drying at a higher temperature leads to a greater change in colour. Thus, the dried leaves showed a much lower intensity of green colour than the fresh leaves. This effect is more pronounced at higher drying temperatures (60 °C) due to chlorophyll degradation.
2. Drying temperatures had a statistically significant effect on the dehydration and rehydration capacity of the dried *A. ursinum* leaves. The higher the drying temperature, the higher the degree of dehydration and rehydration (the pores of the dried food allow water to re-enter the cells). Convection air drying results in considerable moisture removal from the fresh leaves of *A. ursinum* (more than 91%), but the organoleptic quality of the *A. ursinum* leaves is maintained.
3. The drying conditions tested had a significant effect on the total phenolic content and antioxidant activity of *A. ursinum* leaves. An increase in temperature during drying decreased the total polyphenol content in the dried *A. ursinum* leaves.
4. Across the range of measurements, the samples dried at lower temperatures had the higher antioxidant capacity, while the higher drying temperatures resulted in a greater decrease in the antioxidant potential of the dried plant material.
5. *A. ursinum* is considered one of the functional foods for human consumption due to its high nutritional value and prophylactic or therapeutic effects on various diseases. To obtain a high quality dried product, the drying process should ensure a quality comparable to fresh vegetables.

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