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Quality attributes of cultivated white crowberries (*Corema album* (L.) D. Don) from a multi-origin clonal field

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Abstract There is a growing interest in *Corema album* (L.) D. Don fruits due to the unique white colour, mildly acidic lemony flavour and health-promoting properties associated with its bioactive composition. This study performs a physical–chemical characterisation of cultivated *C. album* fruits from a multi-origin clonal field. The field comprises ten wild populations with distinct geographical origins, grown under the same edaphoclimatic conditions. We analysed fruits CIELab colour parameters, texture profile (TPA), pH, acidity (TA, g.100 mL^{-1}), soluble solids content (SSC, %) and total phenolic content (TPC, mg CAE.100 g^{-1}). Our results showed differences between fruits physical–chemical attributes. Variation patterns in fruits SSC and hardness suggest that the differences might be related to the original geographical location of the populations. The determined TPC levels in all samples were very encouraging at a bioactive level, ranging from 185.3 to 355.6 mg CAE.100 g^{-1}. Fruits from Mira and Pego populations stood out from the ten geographical provenances. Mira fruit samples had higher sweetness and lower acidity, while the Pego ones had firmer fruits and higher phenolic content. The multi-origin clonal field allowed us to offer an interesting scientific comparative background, highlighting the large potential of these berries for introduction in the commercial market. Not only our results support the potential of white crowberry as a new crop; the detected differences also indicate a hidden capacity for small fruit market diversification.

Keywords Cultivated plant populations · Geographic provenance · Fruit quality · Hardness · Soluble solids content · Phenolic content

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Introduction

Corema album (L.) D. Don, known as white crowberry, is an Iberian Peninsula endemic species, from the Ericaceae family. The genus *Corema* has an amphi-Atlantic distribution with only two known species: *Corema conradii* (Torr.) Torr. Ex Loud, in the eastern coast of North America and *C. album*, with two subspecies, *C. album* spp. *azoricum* Pinto da Silva in Azores and *C. album* spp. *album* in the Portuguese mainland and Spanish Atlantic coasts (Castroviejo et al. 1993; Li et al. 2002). This evergreen shrub inhabits the coastal dune systems of the Atlantic coast, or even in pine tree understory near the ocean and, in the Iberian Peninsula, it is distributed from the North of Galicia to Gibraltar, in the south (Valdés et al. 1987; Álvarez-Cansino et al. 2012). An isolated population can also be found in Alicante, in the Mediterranean coast of Spain (Martínez-Varea et al. 2019). The species develops blueberry-like fruits shaped in a drupe, with a 5–8 mm diameter, usually with three seeds (Simmonds 1979). Fruit production ranges from July to September, depending on geographical origin. When fully ripe, fruits develop a white or pinkish-white colouration and, depending on genotypes, turn to translucent as maturation progresses (Oliveira and Dale 2012). Still, reports on a winter fructification are known (Alegria et al. 2020) and describe fruit maturation progression from white to black fruits, a newly reported stage.

In both Portuguese and Spanish coastal areas, these berries are part of the traditional folk culture, accounting for their consumption as fresh fruits at beaches and their commercial exploitation in local markets, sold as fresh fruits, made into jams and liquors or even as traditional medicine (Font-Quer and Davit 1993; Gil-López 2011; González 2006). Due to the recently up-raised interest as a novel "fresh beach" fruit, driven by their colour and mildly acidic lemony flavour, efforts are being made to convert this wild species into a new crop for future integration in the berry market (Oliveira and Dale 2012). Moreover, a factor driving agronomic and market possibilities are the *C. album* potential health benefits from its recognised antioxidant properties (Pimpão et al. 2013), a trait evermore demanded by health-conscious consumers.

Existing reports on *C. album* biochemical properties mainly focus on its phenolic profile and antioxidant capacity (Andrade et al. 2017a; Léon-González et al. 2012; Léon-González et al. 2013; Pimpão et al. 2013). Andrade et al. (2017b) and Alegria et al. (2020) also characterised the physical–chemical properties of the white crowberry fruits and defined the maturation progression of the berry in natural conditions. However, all these studies refer to *C. album* fruits collected from wild specimens and, therefore, provide information regarding a single population. *C. album* populations hold distinct genetic backgrounds which could significantly influence fruits physical–chemical attributes (Jacinto et al. 2020), together with local edaphoclimatic conditions (Åkerström et al. 2010; Rohloff et al. 2015). Moreover, Oliveira et al. (2020b) concluded that within the same wild population, different genotypes gather distinct traits of interest, which supports the establishment of a breeding program for the species. Considering the interest for future cropping practices, there is an augmenting need to comparatively test different populations grown in controlled conditions.

This study was designed to compare the physical–chemical properties and the total phenolic content of ten (10) cultivated *C. album* populations established by rooted cuttings of wild plants from different geographical origins, grown under the same edaphoclimatic conditions.

Materials and methods

Sampling

Fruits from female plant individuals were collected from several genotypes, from ten (10) different locations of the Portuguese coast (Fig. 1), grown under the same conditions in Herdade Experimental da Fataca, INIAV, I.P (37°34'56.8"N 8°44'23.6"W), on September 4, 2019. The experimental station is located in Southwest Alentejo and is characterised by an average annual temperature of 17.1 °C and annual precipitation of 516 mm. The white crowberry field was established in 2015, with plants obtained by vegetative propagation (rooted cuttings) from wild plants collected in ten distinct geographical locations (Oliveira et al. 2020a). Plant density is one meter along the line and three meters between lines, with one male plant separating 12 female plants along the line. Irrigation is achieved with drippers separated by 40 cm, watering 2 L h^{-1} twice a month for 30 min. Plants were able to produce significant amount of fruits after three years in the field and its average volume is around 2 m^3. Onwards, we adopt the term

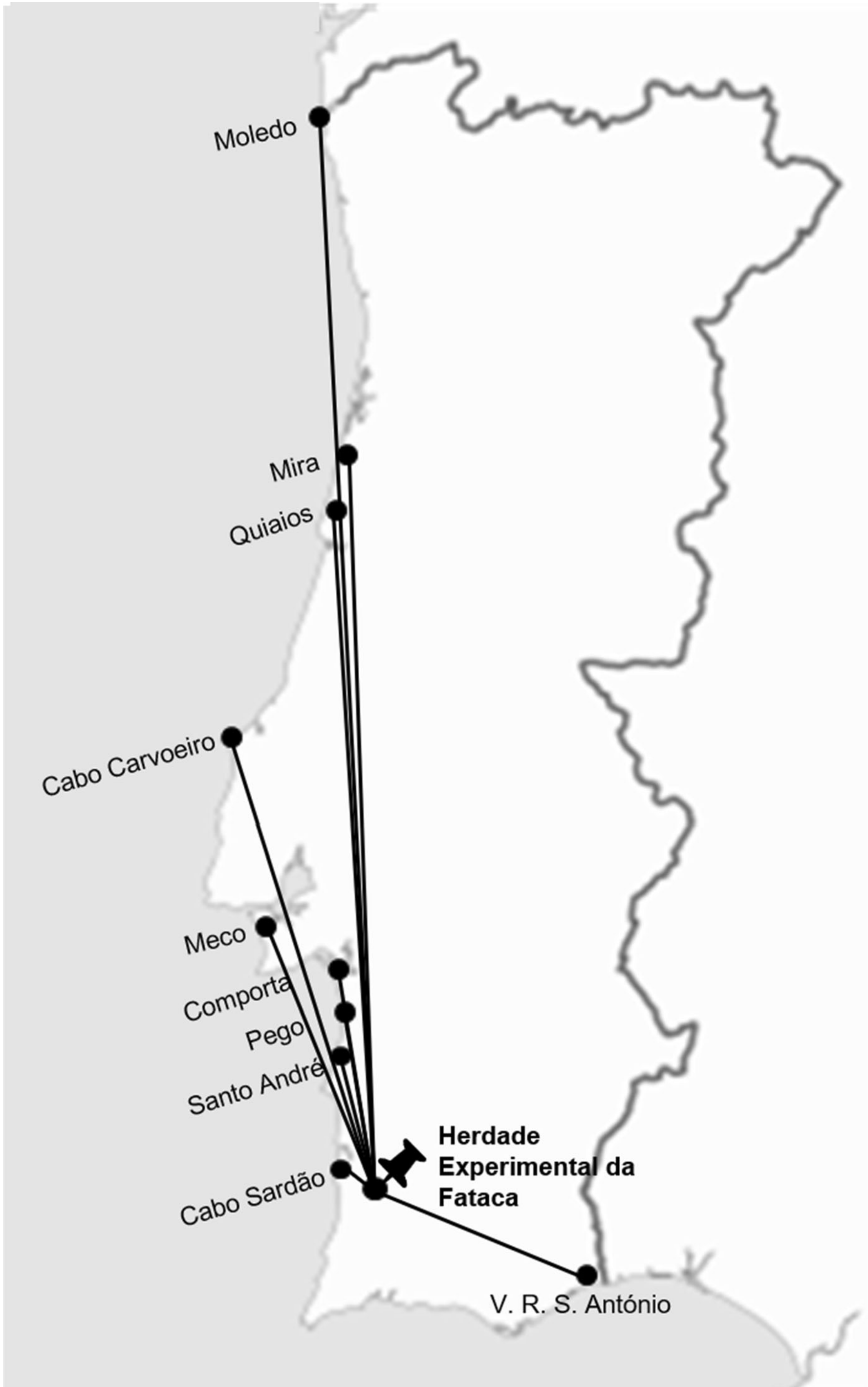

Fig. 1 Location of Herdade Experimental da Fataca (INIAV), and identification of the plant's collection sites for the clonal field establishment

"population" preceded by the original geographic location to identify the cultivated plants present in Fataca.

Only white fruits (the mature stage) were randomly harvested from plants of each provenance, collected in an average of 186 ± 55 g (per replicate, *n* = 3). Fruits were packed in commercial vented clamshell containers (with snap-on lids) placed in a 38 L refrigerated incubator and then transported to the laboratory. At the laboratory, fruits were screened and defective fruits (crushed, cracked, or immature) eliminated. The selected fruits were placed in vented clamshell containers (*n* = 3 per population) for further analysis.

Biometric measurements

For the assessment of biometric characteristics, weight and calibre, all selected fruits from each population were used. The calibre of each fruit sample (based on berries diameter) was sorted with the aid of calibration sieves (∅ 10.25, 8.25, 7.5 mm) and fruits with < 7.5 mm in diameter discarded. Calibrated fruits were then counted on an automated seed counter and weighted on a precision scale.

Colour

Berries superficial colour was evaluated with a CR 300 Minolta colourimeter (Osaka, Japan) by measuring the CIELab parameters (C illuminant, 2nd observer). The instrument was calibrated using a white tile standard (L* = 97.10; a* = 0.08; b* = 1.80). A total of 45 measurements were made per sample type (one measurement per fruit).

Texture

Uniform size fruit samples (*n* = 15 fruits) were used for textural measurements. Prior to analysis, samples were kept for 2 h at room temperature (20 °C) to prevent temperature influence on fruits firmness (Chiabrando et al. 2009). Instrumental texture profile analysis (TPA) was carried out on a TA-XT2i texture analyser (Stable Micro Systems, Godalming, UK) equipped with a 30 kg load cell and HDP/90 platform. Samples were compressed to 30% of the original height using a crosshead speed of 0.8 mm.s^{-1} and a 60 mm diameter cylinder stainless flat probe. Each sample was subjected to a two-cycle compression with 5 s between cycles. Data was collected using Exponent Version 6.1.4.0 software. The following parameters were calculated from the resulting force–time curve: hardness (N); cohesiveness (adimensional); gumminess (N); springiness (mm); chewiness (mJ) and resilience (adimensional).

pH, Soluble solids content and Titrable acidity

The pH and soluble solids content (SSC, %) of freshly prepared juice were determined using a pH meter (Crison Micro pH 2001, Crison Instruments, Spain) and a digital refractometer (DR-A1, ATAGO Co Ltd., Japan), respectively. Titrable acidity (TA) was determined by titrating the freshly prepared juice with 0.1 N NaOH to an endpoint of pH 8.2 using a Mettler Toledo DL21 automatic titrator. Results were expressed as the mass equivalent (g) of citric acid per 100 mL of juice (g.100 mL^{-1}). The pH, SSC and TA determinations were carried out in 15 mL juice triplicates for each sample type and the average values considered.

Total phenolic content

Samples (*n* = 3 per population) were extracted with methanol (1:4, w:v) and the clear supernatant used for the determination of the total phenolic content (TPC) using the Folin-Ciocalteu reagent according to Heredia and Cisneros-Zevallos (2009). Results were expressed as mg chlorogenic acid equivalents per 100 g of fresh tissue (mg CAE.100 g^{-1}).

Statistical analyses

R Studio was used to perform all statistical analyses (R Core Team 2013). To test the differences in physical–chemical properties and total phenolic content among the 10 populations, Kruskall-Wallis tests, at a significance level of $\alpha = 0.05$, were performed, followed by Warden´s post hoc test ($\alpha = 0.05$), for mean separation, with *agricolae* R package (De Mendiburu 2019). Spearman's correlation ($\alpha = 0.05$) was performed (Supporting Information Table S1), using the *Hmisc* R package (Harrell 2014), to seek relations between studied variables and non auto-correlated variables used to perform a Principal Component Analysis (PCA). The PCA was built on eight of the studied variables, using *factorextra* R package (Kassambara and Mundt 2017).

Results and discussion

Among the studied populations, differences emerged on all physical–chemical properties we addressed. These differences however grouped populations according to given parameters, as explained in more details in the following paragraphs.

For biometrics, calibre showed that fruits with a diameter between 8.25 and 10.25 mm were the most common among all samples (Supporting Information Figure S1). 47% to 71% of fruits were within this calibre. In wild populations, similar fruit calibre (in the range of 8.25–10.25 mm) has been reported (Andrade et al. 2017b; Jacinto et al. 2020; Larrinaga and Guitían 2016; Oliveira and Dale 2012); however, in our study, we also found fruits with a diameter > 10.25 mm in samples collected from the Meco, Comporta and Cabo Sardão populations (from 36% up to 47% of the total fruits). On the other hand, also fruits with smaller calibre (7.5–8.25 mm) were frequent, especially in fruits collected from Mira and Quiaios populations (≈30% of the total fruits). Considering a potential future use for fresh fruit production, fruits with higher calibres (> 10.25 mm) potentially represent higher production yields and a more appealing marketability option. Saftner et al. (2008) demonstrated that consumer preference on choosing blueberries from different cultivars was mainly driven by fruit size perception, with larger fruits being preferred over smaller ones, and related to high sensory textural scores (eating quality).

Regarding fruit weight, fruits from the highest calibre (> 10.25 mm) ranged from 0.41 g in VRSTAntónio to 0.71 g in Comporta. Average fruit weight from the most representative calibre (8.25–10.25 mm) was between 0.32 and 0.41 g, and similar fruit weights have been reported in fruits collected from wild plants (Andrade et al. 2017b; Oliveira and Dale 2012; Oliveira et al. 2020b). Also, a study conducted in wild plants from Doñana, Spain, showed that plants with an average canopy size of 0.96 m produce around 2200 fruits with an average weight of ≈ 0.4 g (Zunzunegui et al. 2006). Since the calibre range of 8.25–10.25 mm was the most common among all evaluated samples, fruits from this calibre were selected for colour and texture assessments.

Fruits CIELab colour parameters are reported in Table 1 and indicate significant differences between fruit samples. *Corema album* is known for its white coloured berries. Thus, the luminosity parameter L*, ranging from 0 (pure black) to 100 (pure white), is well suited to differentiate *C. album* fruits colour. Regarding samples L* colour parameter (Table 1), we found differences ($p < 0.05$) among fruits from different plant origins but all related to a white colour perception (L* > 65). We found most evident differences between fruit samples from Santo André and Mira populations (both with L* of ≈69, $p > 0.05$), and VRSTAntónio, Cabo Sardão and Quiaios populations (L* ranging from 74.6 to 76.1, $p > 0.05$). In these latter samples, with higher ($p < 0.05$) L* values, fruit surface lightness was less influenced by variations in red (positive a*) chroma, being perceived as whiter fruits. Reports on the presence of low amounts of anthocyanins are found in *C. album* fruits (León-González et al. 2013), which influences the white/pinkish-white berry perception. Indeed, regarding the a* parameter (Table 1) (sample redness), we found significant differences, with fruit samples from Cabo Carvoeiro, Quiaios, Meco and Comporta populations ($p > 0.05$) representing the lower a* values and of Santo André, Moledo and Pego ($p > 0.05$) populations representing the highest a* values. Notwithstanding the found differences between fruit samples, all samples had positive a* values suggesting that all fruits tend to be, to some extent, more pinkish/reddish than greenish (negative a* values). The higher a* values of fruit samples from the Santo André population supports the lower numerical L* values in regard to those of, e.g., Quiaios, leading to a decreased white perception, probably associated with higher amounts of anthocyanins (León-González et al. 2013). As for the b* values (Table 1), relating to blue (negative values) and yellow (positive values) chromas, despite the found differences ($p < 0.05$), all fruit samples had positive values ranging from 8.07 ± 2.02 (Quiaios) to 11.37 ± 1.98 (Pego). These variations in yellow chromas were more substantial than the ones found for red chromas, leading to the assumption that these variations can also contribute to the overall white colour perception of the fruits.

Among all fruits, those from the Mira population had the highest variability regarding colour parameters: 68.80 ± 8.25, 1.68 ± 3.02, 11.23 ± 3.48 for L*, a*, b*, respectively. Andrade et al. (2017b) assessed wild plants from Mira and reported higher values for L* (79.82 ± 2.82) and lower values for a*

Table 1 CIELab colour parameters of white crowberry fruit samples from Fataca's clonal field, established with plants from ten distinct geographical origins

Sample ID	L*	a*	b*
Moledo	71.75^{ef} ± 3.00	0.99^{ab} ± 0.82	8.51^{bc} ± 1.72
Mira	68.80 ^{fg} ± 8.25	1.68^{bcd} ± 3.02	11.23^{a} ± 3.48
Quiaios	75.62^{ab} ± 4.38	0.24^{ef} ± 0.67	8.07^{c} ± 2.02
Cabo Carvoeiro	72.50^{de} ± 3.89	0.33^{f} ± 0.64	8.99^{b} ± 1.66
Meco	74.20^{bcd} ± 4.57	0.17^{def} ± 0.50	8.65^{bc} ± 1.49
Comporta	73.00^{cde} ± 4.48	0.37^{cdef} ± 0.74	8.36^{bc} ± 1.84
Pego	72.77^{de} ± 4.35	0.66^{abc} ± 0.70	11.37^{a} ± 1.98
Santo André	68.57 ^{g} ± 4.53	1.12^{a} ± 1.08	8.27^{bc} ± 1.66
Cabo Sardão	74.66^{abc} ± 6.11	0.48^{cdef} ± 0.89	8.23^{c} ± 2.11
VRSTAntónio	76.13^{a} ± 4.56	0.48^{cde} ± 0.56	8.61^{bc} ± 1.85

L* values represent the luminosity of samples (0-black to 100-white),

a* and b* values indicate the variation of greenness to redness (−60 to +60) and blueness to yellowness (−60 to +60), respectively

Within a column, different letters represent significant differences at p = 0.05 (Warden's post hoc test)

(1.27 ± 2.05) and b* (5.88 ± 2.1). These differences could possibly be related to the distinct edaphic-climatic conditions of growing sites, influencing pigment synthesis, as documented in blueberry (Howell et al. 2001; Routray et al. 2011). Nevertheless, other mechanisms apart from climatic context might influence fruit colour seeing as we also found colour differences of similar range between fruit samples from the Fataca collection. Díaz-Barradas et al. (2016) assessed *C. album* wild fruits reflectance spectra from plants of Doñana, Spain, finding that berries reflectance is related mainly to two pentacyclic triterpenes, ursolic and oleanolic acid. Thus, the found differences in colour parameters, particularly in L*-values, might be due to different amounts of triterpenes present in the berries.

The results of white crowberries' texture profile (TPA) are shown in Fig. 2 and Supporting Information Table S2. From the evaluated texture parameters, hardness was the parameter that best represented textural differences in white crowberry fruits (Fig. 2). Fruit's hardness varied from 3.9 ± 0.8 N (VRSTAntónio) to 7.7 ± 2.2 N (Pego). Moreover, from Fig. 2, it is possible to observe an interesting pattern regarding fruit samples hardness, describing a visible bell-shaped pattern related to the geographical origin of the Fataca populations. Fruit samples from Comporta, Pego and Santo André populations have significantly higher hardness values than remaining populations. This pattern suggests that fruits from these populations, originally located in the northern shores of the Alentejo Litoral region (Fig. 1), have a significantly different textural imprint regarding the other populations, originally located to the north and south of this cluster. This behaviour might be linked to specific functional traits contingent on a "memory effect", most likely genetic, related to the particular "in natura" geographical origins/environmental conditions.

In literature, textural properties of *C. album* fruits are only described in reference to wild fruits from Mira (Andrade et al. 2017b), reporting values of ca. 1.9 N for hardness. Despite differences in texture determination methodology, the reported values are much lower than the ones determined in the cultivated fruits collected from the Fataca population (Mira; 5.0 ± 1.9 N). As previously mentioned, we should not rule out the differences in environmental conditions from each location (Mira and Fataca's). For instance, Lobos et al. (2018) assessed different irrigation conditions in blueberry (cv. Brigitta) plants and demonstrated that plants under deficit irrigation had firmer fruits. Although plants in Fataca were sparsely irrigated, the drier environmental conditions in the site might have influenced fruits textural attributes, leading to firmer fruits. Moreover, in blueberries, Ochmian et al. (2009) reported that soil composition also has a significant effect on fruit

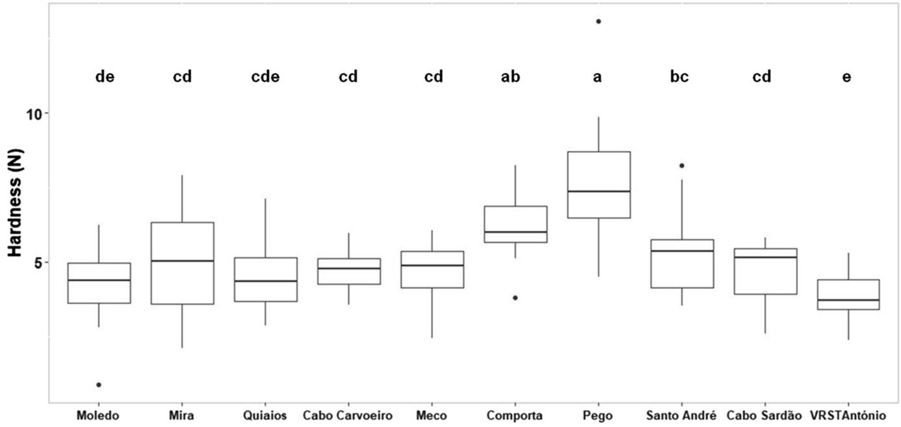

Fig. 2 Hardness of white crowberry fruit samples from Fataca's clonal field, established with plants from ten distinct geographical origins. Significant differences between fruit samples are denoted with a different letter. $n = 15$ per fruit sample

quality, including firmness, which can similarly contribute to explain the found differences between studies.

Mean values (± SD) of fruit samples soluble solids content (SSC), pH, titrable acidity (TA) are shown in Table 2. The distinctive taste found in *C. album*, sweet–sour or acidic taste, makes sugar concentration and pH important parameters for assessing fruits quality. SSC expresses an approximate measure of the amount of sucrose (g) per 100 g of solution. We found significant differences ($p < 0.05$) regarding fruit samples SSC, ranging from 8.2 ± 0.2% (VRSTAntónio) to 10.6 ± 0.1% (Mira), higher than the ones reported in other works in wild *C. album* fruits (Alegria et al. 2020; Andrade et al. 2017b; Pimpão et al. 2013). We found a decreasing trend regarding fruit samples SSC, which can possibly be related to the original geographical location of the populations. The decrease tendency is compliant to the north–south positioning of the wild *C. album* populations from which Fataca's clonal field was established. Again, since the edaphic-climatic context is the same for all sampled plants/fruits, the found differences might be related to adaptation strategies of the wild populations to local factors and specific climate conditions which are "passed on" through a form of "genetic memory". This "memory effect" could, therefore, influence plants functional traits and, consequently, fruit quality (in this case, sugar content).

Table 2 Quality parameters of pH, soluble solids content (SSC) and titrable acidity (TA) of white crowberry fruit samples from Fataca's clonal field, established plants from ten distinct geographical origins

Sample ID	pH	SSC (%)	TA (g.100 ml^{-1})
Moledo	$2.98^{b} \pm 0.02$	$9.17^{c} \pm 0.12$	$10.85^{g} \pm 0.03$
Mira	$3.24^{a} \pm 0.03$	$10.57^{a} \pm 0.06$	$6.77^{i} \pm 0.07$
Quiaios	$2.89^{bc} \pm 0.04$	$9.10^{c} \pm 0.10$	$14.19^{c} \pm 0.11$
Cabo Carvoeiro	$2.69^{f} \pm 0.02$	$9.37^{b} \pm 0.06$	$11.75^{e} \pm 0.10$
Meco	$2.62^{g} \pm 0.02$	$8.83^{d} \pm 0.15$	$14.49^{b} \pm 0.12$
Comporta	$2.79^{de} \pm 0.01$	$9.13^{c} \pm 0.15$	$9.95^{h} \pm 0.07$
Pego	$2.80^{de} \pm 0.05$	$9.03^{cd} \pm 0.06$	$12.62^{d} \pm 0.07$
Santo André	$2.84^{cd} \pm 0.01$	$8.43^{e} \pm 0.06$	$11.93^{e} \pm 0.13$
Cabo Sardão	$2.76^{e} \pm 0.02$	$8.47^{e} \pm 0.15$	$11.02^{f} \pm 0.07$
VRSTAntónio	$2.67^{f} \pm 0.02$	$8.17^{f} \pm 0.15$	$16.53^{a} \pm 0.13$

Within a column, different letters represent significant differences at $p = 0.05$ (Warden's post hoc test)

All fruit samples had low pH values (Table 2), ranging from 2.6 to 3.2 pH units, which is similar to the reported by Alegria et al. (2020) and to the ranges reported for different blueberry cultivars (Chiabrando et al. 2009; Giovanelli and Buratti 2009; Liu et al. 2019). Even though we found statistical differences between fruit samples, differences were, at most, of 0.5 pH units, which does not relate to any expressive physiological outcome. Nevertheless, the low pH values label *C. album* fruits as acidic and promote microbial development inhibition, therefore contributing to fruit preservation. Titrable acidity (TA, Table 2) showed to be coincident with sample pH, with low TA corresponding to high pH and vice-versa. White crowberries are described as high acidity fruits (Andrade et al. 2017b; Pimpão et al. 2013). Pimpão et al. (2013) alluded that such high acidity might be a concerning issue for fresh consumption. However, it also creates an opportunity window for other commercial valorisation strategies, namely as a food additive, as suggested by Alegria et al. (2020).

Fruit sample total phenolic content (TPC) was determined, and results shown in Fig. 3. Reports on high contents of phenolic compounds in wild white crowberry fruits are closely related to the fruits antioxidant properties (Andrade et al. 2017a; Léon-González et al. 2012; Léon-González et al. 2013; Pimpão et al. 2013). In our study, fruit sample TPC levels ranged from 185.3 to 355.6 mg CAE.100 g^{-1}. Among evaluated fruit samples, the fruits from the Pego population stand out with the highest TPC levels, 1.5 times higher than the average TPC values for all samples. Nonetheless, the determined TPC levels ascribe to *C. album* fruits a high antioxidant potential, irrespective of populations geographical origin.

As previously mentioned, several studies reported high contents of phenolics in *C. album* fruits: 12 mg GAE/g (dw) (Pimpão et al. 2013); 1214.4 ± 122 mg GAE/kg (fw) and 7316.6 ± 740 mg GAE/kg (dw) (Léon-González et al. 2013); 1997 ± 75 mg GAE/100 g (Andrade et al. 2017a) and 1393.91 ± 0.06 mg/100 g characterised in a water extract (Léon-González et al. 2012). These studies agree on the high antioxidant potential of the *C. album* fruits, attributed to the phenolic composition which supports our results. The high phenolic content has been related particularly to the high amounts of phenolic acids, with benzoic and hydrocynnamic acids, especially chlorogenic acid, reported as the most abundant phenolic. Considering that phenolic acids are the main group of phenolics found in *C. album* fruits, it is also possible that this prevalent composition influences the acidic taste perception (Tomás-Barberán and Espín 2001).

We used a Principal Component Analysis (PCA) to explore which physical–chemical traits best describe the differences among fruits of cultivated *C. album* populations. We used eight non auto-correlated variables (Supporting Information Table S1) for the PCA: the L*, a*, b* colour parameters, hardness and the pH, SSC, TA and TPC parameters. The obtained PCA (Fig. 4) accounted for 79.5% of the total variance on the first two axes (53.4% and 26.2%, in PC1 and PC2, respectively). The original data variability explained in the first two dimensions is considered suitable to

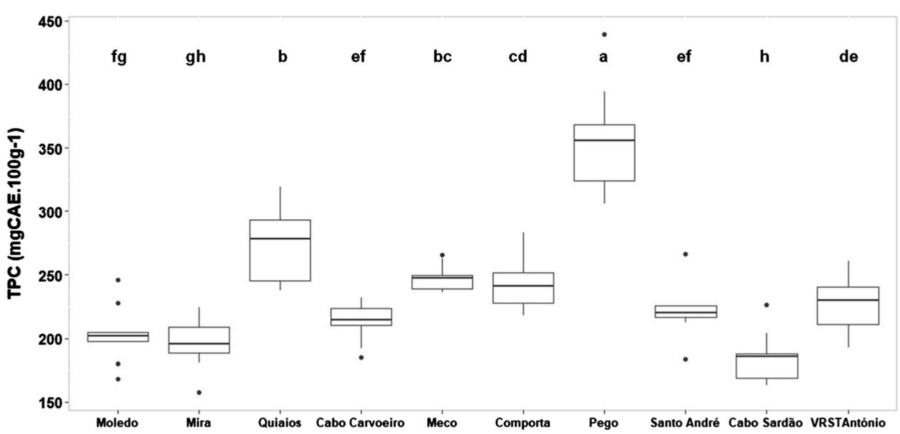

Fig. 3 Total Phenolic Content (TPC) of white crowberry fruit samples from Fataca's clonal field, established with plants from ten distinct geographical origins. Significant differences between fruit samples are denoted with a different letter. $n = 9$ per fruit sample

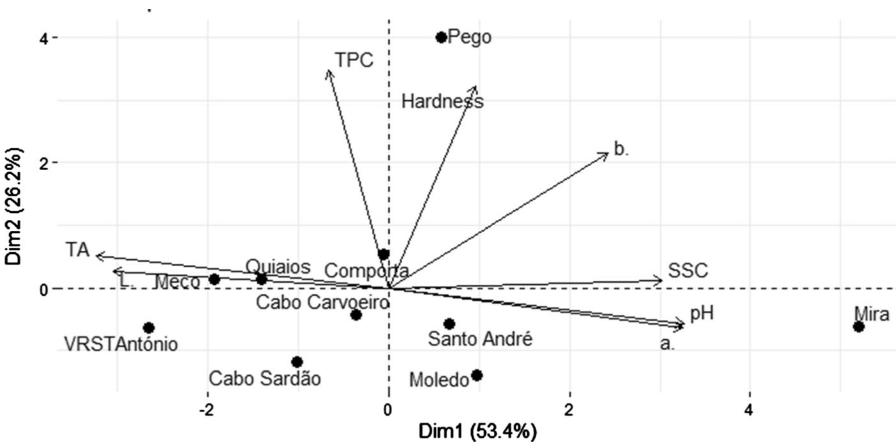

Fig. 4 Principal component analysis (PCA) of white crowberry fruit samples from Fataca's clonal field, established with plants from ten distinct geographical origins. For traits considered see methods section. PCA abbreviations are the following: **TPC** (Total Phenolic Content); **SSC** (Soluble Solids Content); **TA** (Titrable Acidity); L. (L* colour parameter); **a** (a* colour parameter); **b** (b* colour parameter)

define a good qualitative model as a significant percentage of the original information (> 70%) accumulates within the first two PC's (Larrigaudière et al. 2004). The first axis (PC1) was most heavily loaded by pH, SSC, TA and two colour parameters (L* and a*), while the second axis (PC2) was heavily loaded by hardness and total phenolic content (Supporting Information Table S3). The PCA confirms a major cluster, grouping eight of the ten fruit samples, with samples from the Pego and Mira populations independently segregated (Fig. 4). The segregation of the Mira population, established by PC1, relates to the pH and the SSC ($r > 0.80$) and with L*, a* and TA ($r < -0.8$), distinguishing fruits with sweeter traits and pinkish-white colour perception. On the other hand, the segregation of the Pego sample relied mostly on the TPC and hardness vectors, both positively correlated with PC2 ($r > 0.85$), indicating that this sample is distinguished by its high phenolic levels and firmer fruits.

Conclusions

This study contributes to the valorisation of *Corema album* and is the first focused on the quality evaluation of cultivated white crowberry fruits from multiple origins. On the base of specific fruit quality attributes from which this species might be desirable (e.g. acidity, SSC), and despite minor differences, most fruits were similar. From the ten different geographical origins studied, grown under the same conditions in Fataca, only fruits from Mira and Pego populations were clearly segregated. The dissociation was based on fruit sweetness (SSC), firmness, and phenolic content. These specific quality attributes might be linked to specific functional traits conditional to a "memory effect", most likely genetic, related to adaptation strategies of the wild populations to local factors and specific climate conditions. In this context, it will be important to understand how different cultivation conditions (emulating the natural habitat) affect fruit quality and to select appropriate genotypes for the viability of a crop with the desirable quality characteristics. The white crowberry has an interesting physical–chemical profile and high phenolic content, supporting its evaluation as a new crop for a potential small fruit market expansion.

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Compliance with ethical standards

Conflicts of interest The authors have no conflict of interest to report. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

Availability of data and material The data that support the findings of this study are available from the corresponding author, CA, upon reasonable request.

References

Åkerström A, Jaakola L, Bång U, Jaderlund A (2010) Effects of latitude-related factors and geographical origin on anthocyanidin concentrations in fruits of *Vaccinium myrtillus* L. (bilberries). J Agric Food Chem 58(22):11939–11945. https://doi.org/10.1021/jf102407n

Alegria C, Abreu M, Máguas C, Giovanetti M (2020) Winter collection of the underutilized berry *Corema album* (L.): new insights on its maturation progression. Agri Res Tech Open Access J. 24(4):556274. https://doi.org/10.19080/ARTOAJ.2020.24.556274

Álvarez-Cansino L, Díaz-Barradas MC, Zunzunegui M, Esquivias MP, Dawson TE (2012) Gender-specific variation in physiology in the dioecious shrub *Corema album* throughout its distributional range. Funct Plant Biol 39(12):968–978. https://doi.org/10.1071/FP12131

Andrade SC, Guiné RP (2017) Gonçalves FJ (2017a) Evaluation of phenolic compounds, antioxidant activity and bioaccessibility in white crowberry (*Corema album*). J Food Meas Charact 11(4):1936–1946. https://doi.org/10.1007/s11694-017-9576-4

Andrade SC, Gonçalves F, Guiné R (2017) Contribution for the physical-chemical characterization of Portuguese Crowberry (*Corema album*). Int J Food Sci Nutr 2(4):9–14

Castroviejo S, Aedo C, Gómez Campo C, Laínz M, Montserrat P, Morales R, Muñoz Garmendia F, Nieto Felinier G, Rico E, Talavera S, Villar L (1993) Flora Ibérica. Plantas vasculares de la Península Ibérica e Islas Baleares. Cruciferae-Monotropaceae Vol. IV. Real Jardim Botánico, C.S.I.C., Madrid. https://bibdigital.rjb.csic.es/idurl/1/9900

Chiabrando V, Giacalonea G, Rolle L (2009) Mechanical behaviour and quality traits of highbush blueberry during postharvest storage. J Sci Food Agric 89:989–992. https://doi.org/10.1002/jsfa.3544

De Mendiburu F (2019) Agricolae: statistical procedures for agricultural research. R package version. 1.3-1. http://cran.r-project.org/package=agricolae

Diaz-Barradas MC, Costa C, Correia O, León-González AJ, Navarro-Zafra I, Zunzunegui M, Álvarez-Cansino L, Martín-Cordero C (2016) Pentacyclic triterpenes responsible for photoprotection of *Corema album* (L.) D. Don white berries. Biochem Syst Ecol 67:103–109. https://doi.org/10.1016/j.bse.2016.05.009

Font-Quer P (1993) Plantas medicinales: El Dioscórides renovado. Labor, Barcelona

Gil-López MJ (2011) Etnobotánica de la camarina (Corema album, Empetraceae) en Cádiz. Acta Bot Malacitana 36:137–144. https://doi.org/10.24310/abm.v36i1.2784

Giovanelli G, Buratti S (2009) Comparison of polyphenolic composition and antioxidant activity of wild Italian blueberries and some cultivated varieties. Food Chem 112(4):903–908. https://doi.org/10.1016/j.foodchem.2008.06.066

González G (2006) Los árboles y arbustos de la Península Ibérica e Islas Baleares. Mundi-Prensa, Madrid

Harrell Jr FE (2014) Hmisc package version 4.1-1. https://cran.r-projects.org/package=Hmisc

Heredia JB, Cisneros-Zevallos L (2009) The effect of exogenous ethylene and methyl jasmonate on pal activity, phenolic profiles and antioxidant capacity of carrots (*Daucus carota*) under different wounding intensities. Postharvest Biol Technol 51(2):242–249. https://doi.org/10.1016/j.postharvbio.2008.07.001

Howell A, Kalt W, Duy JC, Forney CF, McDonald JE (2001) Horticultural factors affecting antioxidant capacity of blueberries and other small fruit. Horttechnology 11(4):523–528. https://doi.org/10.21273/HORTTECH.11.4.523

Jacinto J, Oliveira PB, Valdiviesso T, Capelo J, Arsénio P, Nóbrega F (2020) Genetic diversity assessment among *Corema album* (L.) D. Don (Ericaceae) genotypes based on ISSR markers and agro-morphological traits. Genet. Resour. Crop Evol. 67(3):715–726. https://doi.org/10.1007/s10722-019-00849-8

Kassambara A, Mundt F (2017) Factoextra: extract and visualize the results of multivariate data analyses. R package version 1.0.4. https://cran.r-project.org/package=factoextra

Larrigaudière C, Lentheric I, Puy J, Pintó E (2004) Biochemical characterisation of core browning and brown heart disorder in pear by multivariate analysis. Postharvest Biol Technol 31:29–39. https://doi.org/10.1016/S0925-5214(03)00132-7

Larrinaga AR, Guitián P (2016) Intraspecific variation in fruit size and shape in *Corema album* (Ericaceae) along a latitudinal gradient: from fruits to populations. Biol J Linn Soc Lond 118(4):940–950. https://doi.org/10.1111/bij.12794

León-González AJ, Mateos R, Ramos S, Martín MÁ, Sarriá B, Martín-Cordero C et al (2012) Chemo-protective activity and characterization of phenolic extracts from *Corema* *album*. Food Res Int 49(2):728–738. https://doi.org/10.1016/j.foodres.2012.09.016

León-González AJ, Truchado P, Tomás-Barberán FA, López-Lázaro M, Díaz-Barradas MC, Martín-Cordero C (2013) Phenolic acids, flavonols and anthocyanins in *Corema album* (L.) D. Don berries. J Food Compost Anal 29(1):58–63. https://doi.org/10.1016/j.jfca.2012.10.003

Li J, Alexander Iii J, Ward T, Del Tredici P, Nicholson R (2002) Phylogenetic relationships of Empetraceae inferred from sequences of chloroplast gene matK and nuclear ribosomal DNA ITS region. Mol Phylogenet Evol 25(2):306–315. https://doi.org/10.1016/S1055-7903(02)00241-5

Liu B, Wang K, Shu X, Liang J, Fan X, Sun L (2019) Changes in fruit firmness, quality traits and cell wall constituents of two highbush blueberries (*Vaccinium corymbosum* L.) during postharvest cold storage. Sci Hortic 246:557–562. https://doi.org/10.1016/j.scienta.2018.11.042

Lobos TE, Retamales JB, Ortega-Farías S, Hanson EJ, López-Olivari R, Mora ML (2018) Regulated deficit irrigation effects on physiological parameters, yield, fruit quality and antioxidants of *Vaccinium corymbosum* plants cv. Brigitta Irrig Sci 36(1):49–60. https://doi.org/10.1007/s00271-017-0564-6

Martínez-Varea CM, Ferrer-Gallego PP, Raigón MD, Badal E, Ferrando-Pardo I, Laguna E, Villaverde V (2019) *Corema album* archaeobotanical remains in western Mediterranean basin. Assessing fruit consumption during Upper Palaeolithic in Cova de les Cendres (Alicante, Spain). Quatern Sci Rev 207:1–12. https://doi.org/10.1016/j.quascirev.2019.01.004

Ochmian I, Grajkowski J, Skupień K (2009) Influence of substrate on yield and chemical composition of highbush blueberry fruit cv Sierra. J Fruit Ornam Plant Res 17(1):89–100

Oliveira PB, Dale A (2012) *Corema album* (L.) D Don, the white crowberry—a new crop. J Berry Res 2(3):123–133. https://doi.org/10.3233/JBR-2012-033

Oliveira PB, Luz FR, Magalhães T, Lisboa A, Oliveira CM, Valdiviesso T (2020a) Propagação vegetativa e seminal em *Corema album* (L.) D. Don Actas Portuguesas de Horticultura 30:347–356

Oliveira PB, Valdiviesso T, Luz FR (2020b) Melhoramento Genético da camarinha; Seleção e Avaliação de plantas. Actas Portuguesas de Horticultura 30:338–346

Pimpão RC, Dew T, Oliveira PB, Williamson G, Ferreira RB, Santos CN (2013) Analysis of phenolic compounds in Portuguese wild and commercial berries after multienzyme hydrolysis. J Agric Food Chem 61(17):4053–4062. https://doi.org/10.1021/jf305498j

R Core Team. R: A language and environment for statistical computing (2013) R foundation for statistical computing, Vienna, Austria. ISBN 3-900051-07-0. http://www.Rproject.org/

Rohloff J, Uleberg E, Nes A, Krogstad T, Nestby R, Martinussen I (2015) Nutritional composition of bilberries (*Vaccinium myrtillus* L.) from forest fields in Norway-Effects of geographic origin, climate, fertilization and soil properties. J Appl Bot Food Qual 88:274–287. https://doi.org/10.5073/JABFQ.2015.088.040

Routray W, Orsat V (2011) Blueberries and their anthocyanins: factors affecting biosynthesis and properties. Compr Rev Food Sci Food Saf 10(6):303–320. https://doi.org/10.1111/j.1541-4337.2011.00164.x

Saftner R, Polashock J, Ehlenfeldt M, Vinyard B (2008) Instrumental and sensory quality characteristics of blueberry fruit from twelve cultivars. Postharvest Biol Technol 49(1):19–26. https://doi.org/10.1016/j.postharvbio.2008.01.008

Simmonds NW (1979) Principles of crop improvement. Longman, Harlow, p 408

Tomás-Barberán FA, Espín JC (2001) Phenolic compounds and related enzymes as determinants of quality in fruits and vegetables. J Sci Food Agric 81(9):853–876. https://doi.org/10.1002/jsfa.885

Valdés B, Talavera S, Fernández Galiano E (1987) Flora vascular de Andalucía Occidental. Ketres, Barcelona

Zunzunegui M, Díaz-Barradas MC, Clavijo A, Álvarez-Cansino L, Lhout FA, Novo FG (2006) Ecophysiology, growth timing and reproductive effort of three sexual foms of *Corema album* (Empetraceae). Plant Ecol 183(1):35–46. https://doi.org/10.1007/s11258-005-9004-4