



Phenotypic Characterization of a Wild-Type Population of Cornelian Cherries (*Cornus mas* L.) from Austria

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Abstract

Cornelian cherry (*Cornus mas* L.) belongs to a group of fruit and nut species growing in Europe considered to be underused economically, although it has been recognized as a potential regional “superfood” and as a source of valuable bioactive compounds. Phenotyping fruits of 30 accessions of an Austrian wildtype population of *C. mas* allowed to evaluate their nutraceutical potential. Ten fruits per accession were characterized by morphological and morphometric approaches. Biochemical analyses were performed to determine the respective amounts of vitamin C, sugars, anthocyanins, iridoids and flavonoids. Both datasets were subjected to statistical analyses. Morphological and morphometric characterization and biochemical analyses enabled the identification of the individuals with the highest economic value. Statistical treatment of data identified the most significant principal components. The first phenotypic profiling of bioactive compounds of wildtype *C. mas* in Austria yielded a high variability. Dealing with wildtype plants, this is not surprising. However, our results allow to select among the Austrian *C. mas* accessions the most interesting individuals for further breeding of this alternative fruit with interesting nutritional values.

Keywords Fruit characteristics · Principal components · Cyanidin 3-*O*-galactoside · Pelargonidin-3-*O*-galactoside · Quercetin-3-*O*-glucuronide

Introduction

The genus *Cornus* belonging to the family *Cornaceae* comprises about 65 species, characterized by colourful and attractive flowers and fruits (Yilmaz et al. 2009). Most *Cornus* species are used as ornamentals, such as *Cornus florida* or *Cornus kousa*, while only few species are grown for their fruits, including *Cornus mas* and *Cornus officinalis* (Ercisli et al. 2011, Czerwińska and Melzig 2018).

Cornus mas L. (Cornelian cherry, European cornel or dogwood) is predominantly distributed over Southern and Central Europe, the Black Sea basin and the Caucasus (Da Ronch et al. 2016; Schramayr 2009).

Cornus mas has been used as food and as a medicinal plant for millennia in Eurasia (Gismondi et al. 2012), and all parts of the plant are valuable (Dinda et al. 2016; Czer-

wińska and Melzig 2018). Cornelian cherry fruit stones moreover may have had a symbolic role in funerary rituals by the Mesolithic community (Filipović et al. 2020). Their fruits are a rich source of vitamin C, polyphenols, organic acids, sugars, and minerals (Seeram et al. 2002; Tural and Koca 2008; Rop et al. 2010; Hassanpour et al. 2011) that might contribute to a healthy nutrition and be considered as a “superfood” (Bayram and Ozturkcan 2020).

Among the most studied bioactive chemical constituent in cornelian cherries, anthocyanins, flavonoid, iridoids and vitamin C are the predominant ones (Dinda et al. 2016, Szczepaniak et al. 2019). Antioxidant activity in cornelian cherries has been attributed to polyphenolic compounds as well as to ascorbic acid (Bajić-Ljubičić et al. 2018; Tural and Koca 2008). There exists ample evidence in vitro and in vivo that Cornelian cherry fruit extracts have antimicrobial, antidiabetic, anti-atherosclerotic, hepatoprotective, neuro-protective, anti-cancer, anti-inflammatory and renal protective, antiplatelet and antiglaucoma activities (Dinda et al. 2016; Perova et al. 2014; Vareed et al. 2006; Zarei et al. 2014; Jayaprakasam et al. 2006; Soltani et al. 2015).

In fruits, the amounts of soluble sugars, including fructose and glucose, not only play an essential role as a source

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of energy, structure and functionality of the whole plant (Ma et al. 2014), but are also essential for the growth and quality of the fruits. The sugar content in *Cornus mas* plays an important role in consumer satisfaction and consumption (Bayram and Ozturkcan 2020). Cornelian cherry fruits are consumed fresh or dried, are used to produce jam, stewed fruit, paste, marmalade, dried fruit pulp and syrup, several types of soft drinks and used for medicinal purposes too (Tural and Koca 2008, Turhan et al. 2007). Fruit extracts are also used in Europe for cosmetic purposes, replacing synthetic astringent substances, and are claimed to exert a favourable action on the human complexion (Polinicencu et al. 1980).

In Austria, Cornelian cherry is the leading species in the Pielach Valley in Lower Austria. As a result of a wide range of products manufactured in the zone, such as jams, drinks, juices, ice creams and vinegars, this area is marketed as a “Valley of Cornelian Cherries” for tourism (Schramayr 2009). Cornelian cherries in Austria have not been systematically studied although their healthy ingredients make

them a potential regional superfood (Borroto Fernandez and Laimer 2021).

Here we describe our effort to select the most interesting individuals among a population of over 400 centenary plants growing wild in the region of the Pielach Valley and two neighbouring valleys (Lower Austria). This was achieved by characterizing both morphological traits, mainly linked to the use as food (such as appearance and taste), and most secondary metabolites such as flavonoids, iridoids and cornusides, which are mainly interesting for health-related effects.

The aim of this study was to provide information about the variability of morphological traits as well as nutrients and pharmaceutical ingredients in 30 *Cornus mas* Austrian accessions. This phenotypic characterization might explore Cornelian cherry accessions as a source of valuable material for further selection in Austria.

Table 1 Developmental characteristics of 30 plants selected from 18 sites in two regions of Austria (G, Gölsen Valley; P, Pielach Valley)

Accession number	Site of origin (P, G)	Above sea level (m)	Age (years)	Fruit size, shape	Fruit colour
1	2, P	320	>50	Medium, elliptical	Medium red
2	3, P	344	>200	Medium, round	Dark red
3	6, P	344	>100	Large, round	Light red
4	7, P	372	>100	Medium, round	Dark red
5	7, P	372	>100	Medium, round	Light red
6	9, G	369	>200	Large elliptical	Yellow
7	9, G	369	>200	Medium, elliptical	Orange
8	9, G	369	>200	Large, elliptical	Light red
9	12, P	572	>200	Large, round	Dark red
10	12, P	572	>100	Large, elliptical	Dark red
11	14, P	600	>100	Medium, round	Medium red
12	15, P	580	>200	Medium, elliptical	Orange
13	15, P	580	>200	Medium, elliptical	Dark red
14	15, P	580	>200	Medium, elliptical	Dark red
15	25, P	600	>100	Large, elliptical	Light red
16	26, P	372	>200	Large, elliptical	Light red
17	26, P	372	>100	Large, elliptical	Dark red
18	29, P	280	10	Medium, round	Medium red
19	29, P	280	10	Large, round	Medium red
20	31, P	500	>100	Medium, round	Orange
21	32, P	600	>200	Medium, elliptical	Medium red
22	32, P	550	>200	Medium, round	Light red
23	33, P	550	>200	Medium, round	Medium red
24	33, P	550	>200	Medium, elliptical	Medium red
25	36, P	400	>100	Large, elliptical	Light red
26	37, P	460	>400	Medium, elliptical	Dark red
27	37, P	460	>200	Large elliptical	Dark red
28	38, G	450	>100	Large, pear shaped	Medium red
29	38, G	450	>100	Large, elliptical	Light red
30	41, P	600	>200	Large, elliptical	Light red

Material and Methods

Plant Material

The entire population of cornelian cherry (*Cornus mas* L.) accessions from the Mostviertel region in Lower Austria comprised more than 400 individuals from 40 sites at different altitudes (280–600 m above sea level), in open and closed forest areas [Borroto and Laimer, unpublished data]. A total of 30 Cornelian cherry (*Cornus mas* L.) accessions, among 152 individuals, were selected from 18 sites in Pielach Valley (P) and Gölsen Valley (G; Table 1). The

selection was made based on distinguished attractivity and famers' preferences.

Plants of different age and with fruits of heterogeneous sizes, shapes and colours were selected (Table 1). According to the age, they were two plants of about 10 years old, one plant older than 50 years, 11 plants older than 100 years, 15 plants older than 200 years, and the oldest plant was older than 400 years. We selected plants with fruits of different sizes, shapes and colours (Table 1). One plant had yellow fruits, which seems a rare mutation, because we only encountered three plants with this phenotype in more than 400 accessions studied. Three plants presented orange fruits, nine had light red fruits, eight medium red

Table 2 Mean values of fruit morphological characteristics of 30 Austrian accessions of Cornelian cherry

Accession number	Fruit weight (g)	Stone weight (g)	Flesh weight (g)	Flesh/stone ratio	Fruit length (mm)	Fruit width (mm)	Index (Fruit length/Fruit width)	Stone Length (mm)	Stone width (mm)	Index (stone length/stone width)	Fruit flesh (%)
1	1.725	0.241	1.48	6.21	15.615	11.933	1.31	12.362	5.65	2.20	86.03
2	2.297	0.339	1.96	5.77	16.160	12.813	1.26	12.437	6.34	1.96	85.14
3	1.952	0.292	1.66	5.76	15.650	12.105	1.29	12.04	6.03	2.01	85.03
4	1.449	0.171	1.28	7.48	15.814	10.646	1.49	11.499	4.97	2.32	88.15
5	2.292	0.268	2.02	7.52	17.674	12.49	1.41	12.705	5.51	2.31	88.20
6	1.382	0.275	1.11	4.04	13.460	9.123	1.48	11.81	5.99	1.98	79.99
7	2.125	0.259	1.87	7.23	16.969	11.791	1.44	12.497	5.57	2.25	87.75
8	2.003	0.257	1.75	6.91	16.218	11.826	1.37	12.232	5.84	2.11	87.16
9	1.624	0.238	1.39	5.88	14.466	11.269	1.28	11.383	5.65	2.02	85.35
10	1.933	0.266	1.67	6.34	16.399	12.191	1.35	12.005	5.76	2.09	86.19
11	1.572	0.247	1.33	5.35	16.122	9.927	1.62	12.903	5.32	2.44	84.02
12	2.396	0.330	2.07	6.31	19.078	13.48	1.42	13.973	6.02	2.33	86.18
13	2.003	0.284	1.72	6.03	16.818	12.039	1.40	12.541	6.08	2.06	85.71
14	2.190	0.348	1.84	5.26	16.263	12.855	1.27	12.904	6.20	2.09	83.86
15	2.242	0.315	1.93	6.13	16.863	12.984	1.30	12.57	5.96	2.12	85.86
16	2.500	0.328	2.17	6.61	18.058	13.767	1.31	12.645	6.14	2.07	86.78
17	1.813	0.247	1.57	6.37	15.737	11.952	1.32	11.559	5.61	2.06	86.32
18	1.950	0.288	1.66	5.80	16.356	11.758	1.39	12.477	5.60	2.23	85.14
19	1.993	0.283	1.71	6.07	16.510	13.187	1.25	12.602	5.91	2.13	85.65
20	2.155	0.282	1.87	6.72	16.392	13.192	1.25	11.875	5.99	1.98	86.90
21	1.740	0.278	1.46	5.46	17.854	11.73	1.52	14.2875	5.46	2.63	83.85
22	1.856	0.257	1.60	6.25	15.143	12.406	1.22	11.303	5.72	1.98	85.82
23	1.892	0.436	1.46	3.36	16.422	12.473	1.32	13.211	6.97	1.90	76.81
24	1.786	0.298	1.49	5.00	16.965	11.904	1.43	12.784	5.98	2.14	83.15
25	2.324	0.408	1.92	4.70	18.226	13.016	1.40	14.23	6.47	2.20	82.32
26	1.771	0.261	1.51	5.99	16.405	11.434	1.43	12.793	5.66	2.26	85.48
27	1.764	0.261	1.50	5.80	14.826	11.674	1.27	11.55	5.79	1.99	85.16
28	1.790	0.273	1.52	5.59	16.433	11.773	1.40	11.906	5.68	2.10	84.72
29	2.577	0.214	2.36	11.15	18.106	13.562	1.34	12.143	4.98	2.46	91.72
30	2.137	0.365	1.77	4.99	17.065	12.85	1.33	12.782	6.35	2.03	82.75
Minimum	1.382	0.171	1.106	3.363	13.460	9.123	1.221	11.303	4.970	1.904	76.810
Maximum	2.577	0.436	2.363	11.155	19.078	13.767	1.624	14.288	6.965	2.634	91.717
Mean	1.974	0.287	1.687	6.069	16.469	12.138	1.363	12.467	5.839	2.149	85.239
Standard deviation	0.298	0.054	0.279	1.324	1.172	1.025	0.092	0.762	0.413	0.168	2.642

Table 3 Correlation coefficients among physical properties in Cornelian cherry genotypes

Variables	1	2	3	4	5	6	7	8	9	10	11
1. Fruit weight (g)	1	0.426*	0.984**	0.415*	0.737**	0.880**	−0.368*	0.365*	0.272	0.041	0.361*
2. Stone weight (g)		1	0.261	−0.609*	0.340	0.447*	−0.220	0.604*	0.916**	−0.355	−0.672**
3. Flesh weight (g)			1	0.562*	0.721**	0.853**	−0.350	0.272	0.112	0.113	0.517*
4. Flesh/stone ratio				1	0.307	0.307	−0.081	−0.277	−0.683**	0.420*	0.931**
5. Fruit length (mm)					1	0.670**	0.183	0.726**	0.069	0.523*	0.261
6. Fruit width (mm)						1	−0.604*	0.298	0.350	−0.089	0.281
7. Index (fruit length/fruit width)							1	0.386*	−0.384*	0.678**	−0.100
8. Stone length (mm)								1	0.351	0.484*	−0.318
9. Stone width (mm)									1	−0.644*	−0.703**
10. Index (stone length/stone width)										1	0.377*
11. Fruit flesh (%)											1

*, **Correlation coefficient is significant at $p < 0.05$ and $p < 0.0001$, respectively

and nine dark red fruits. Approximately 100 g of fruits from these accessions were picked at the stage of full maturity.

Morphological Characteristics

Each sample for the morphological analysis consisted of 10 fully matured fruits and they were evaluated for their morphological characteristics (Table 2). Stone weight and fruit weight were measured using a digital bench balance with a sensitivity of 0.001 g. Fruit length (mm), fruit width (mm), stone width (mm) and stone length (mm) were measured by a digital calliper with a resolution of 0.01 mm (Walter®, Salzburg, Austria). Fruit flesh ratio was counted considering fruit and seed weight; flesh/seed ratio was calculated by mean fruit weight–mean seed weight/mean seed weight.

Bioactive Compounds

After stone extraction, fruit flesh underwent chemical analyses including for vitamin C, fructose, glucose, cornuside (Cor), cyanidin 3-*O*-galactoside (Cy 3-Gal), loganic acid (LA), quercetin-3-*O*-glucuronide (Q 3-Glr) and pelargonidin-3-*O*-galactoside (Pg 3-Gal).

Fructose and glucose were determined using high-performance liquid chromatography (HPLC) and evaporative light scattering (ELSD) detection following a modified protocol for conventional methodology (DIN 10757:1997-05; 1997).

For Cor, Cy 3-Gal, LA, Q 3-Glr and Pg 3-Gal, a modified HPLC procedure (Grauer 2016) was adopted.

Vitamin C in an exploratory analysis was measured on a reduced number of accessions by HPLC-UV and electrochemical detection after ascorbic acid was extracted from the sample matrix with an acetonitrile-based solu-

tion and isoascorbic acid was used as an internal standard (AGROLAB, Kiel, Germany.).

Statistical Analysis

Data recording for the morphological characteristics and chemical composition was performed in Microsoft Excel 2019 (Microsoft, Redmont, WA, USA). Morphological data were subjected to ANOVA and a post hoc Tukey's HSD test to separate and compare means if significant differences ($p < 0.05$) were detected. Physical properties were calculated using Pearson's correlation coefficient. Mean, maximum, minimum, and standard deviation (SD) values for the chemical characteristics in the study were calculated (Table 3). The morphological and chemical characteristics (except vitamin C) were analysed by principal component analysis (PCA). The results of the PCA were used to construct two-dimensional scatter plots of the first two factors. Statistical analyses were performed using the XLSTAT statistical software program (Addinsoft Inc., New York, NY, USA).

Results and Discussion

Morphological Characteristics

The present study found statistical differences in all morphological traits among the 30 accessions of Cornelian cherry analysed ($p < 0.05$). Table 2 shows mean values of the morphological characteristics determined in 30 Austrian accessions.

The average fruit weight of Cornelian cherry in this study ranged from 1.38 g to 2.58 g, which is within the range of 1–10 g of previous studies observed in Iran (Hassanpour et al. 2012), Serbia (Bijelić et al. 2011; Mratinić et al.

2015), Montenegro (Jaćimović et al. 2015), Poland (Szot et al. 2019) and Turkey (Yilmaz et al. 2009), although a Serbian genotype with 14.55 g of fruit weight was described (Bošnjaković et al. 2012). An important question associated with the dimension of the Serbian genotype can be attributed to the fact that the genotypes under study were from secondary populations (Bošnjaković et al. 2012). The fruit flesh weight was between 1.1 g and 2.36 g; however, this value was reported to be higher in Iran (Hassanpour et al. 2012).

The length and width of the fruits in the selected Austrian accessions varied from 13.46 mm to 19.08 mm and 9.12 mm to 13.77 mm, respectively, which is consistent with the results of other studies where fruit lengths are between 10 and 23 mm (Bayram and Ozturkcan 2020) and fruit width between 7.43 and 23.51 mm depending on the region (Yilmaz et al. 2009, Bijelić et al. 2011; Hassanpour et al. 2012).

Interestingly, the fruit length/width index and the stone length/width index, correspond exactly to the fruit and stone shape, respectively. Thus, the described fruit shape (round or elliptical) could be objectively confirmed and calculated with this index.

Obviously, the farmers prefer plants with large fruits of different colours, which make the harvest easier. However, there is no way to correctly judge the yield from the exterior appearance (length and width) and the weight of the fruits, since it is the proportion of the kernels that finally determines the fruit flesh percentage that can be obtained from the crop. Instead, we would like to argue that the last column in Table 2 (% fruit flesh) contains the value of most interest for the farmers. Nevertheless, one should keep the caveat in mind that this might vary in this rain-fed crop with the availability of annual precipitations.

Among the plants analysed, two were in the range of 76.81–79.99%. Usually they would be discarded, unless they had another interesting trait, which for plant 6 is clearly the yellow fruit colour. Usually, plants with yellow fruit are considered less vigorous (Pirc, personal communication); however, the administration of yellow fruit extracts of *Cornus mas* increased the level of reduced glutathione and mean cell haemoglobin in diabetic rats (Dzydzan et al. 2019).

In the medium range, which encompassed the majority of the accessions, we found ten plants with 85.03–85.86% fruit flesh and six plants with 86.03–86.90% fruit flesh. In the high range we found two plants with 87.16–87.75% fruit flesh, two plants with 88.15–88.20% fruit flesh and a single plant with 91.72% fruit flesh.

Plant 29 had large elliptical light red fruits with an attractive appearance and the heaviest fruits with the highest flesh weight. This plant also had the highest percentage of fruit flesh. Plant 6 was the plant with the lightest and smallest fruits, and the second lowest percentage of fruit flesh with medium-sized elliptical fruits, but of a yellow

colour. Plant 12 with the longest and second widest fruits had large elliptical fruits of an orange colour. The fruits of plant 23, which were catalogued as medium round and medium red, possessed the heaviest stone weight; in fact, plant 23 had the lowest fruit flesh percentage.

Plant 16 had the roundest fruits and the second highest fruit weight and a high fruit flesh percent. Plant 4 had medium-sized, round, dark fruits with the narrowest stone width and the lowest stone weight, and a high percentage of fruit flesh.

Interestingly, plants 21 and 22, which stood close to 32, represent two extremes: Plant 21 had the longest kernels and the highest stone length/width index, medium elliptical size, medium red fruits with a lower percentage of fruit flesh; while plant 22 had the shortest stones with a medium percentage of fruit flesh, medium size, round and medium red fruits.

Table 3 shows the Pearson correlation matrix for the morphological traits in this study with a significant positive correlation. There was a significant positive correlation between fruit weight, fruit length, fruit width and flesh weight. Stone weight is positively correlated with stone width. The flesh/stone ratio is positively correlated with fruit flesh and negatively correlated with stone width. Fruit length is positively correlated with the stone length. Fruit width is negatively correlated with the index of fruit length/fruit width. The index of fruit length/fruit width is positively correlated with the index of stone length/stone width. The stone width is negatively correlated with the index of stone length/stone width as well as with the percentage of fruit flesh.

The observed correlation between fruit weight and fruit width would also allow us to sort *Cornus mas* in Austria according to the fruit width, contrary to what was observed by Hassanpour et al. (2012). Instead, we would like to argue that the percentage fruit flesh (last column in Table 2) contains the value of most interest for the farmers.

Bioactive Compounds

It has been claimed that Cornelian cherry fruits contain twice as much ascorbic acid (vitamin C) as oranges (Seeram et al. 2002); however, it could fluctuate between 11 and 360 mg/100 g (Bayram and Ozturkcan 2020). Although the vitamin C values from Pielach Valley recorded in this study are lower than other genotypes examined in Iran (240–360 mg/100 g; Hassanpour et al. 2011, 2012), the differences in the values of vitamin C could depend on the cultivar, cultivation condition, genotype as well as the methods used for content determination (Bayram and Ozturkcan 2020).

The vitamin C content for all Cornelian cherry analysed varied from 5.08 to 92.10 mg/100 g with an average of 29.82 mg/100 g. Our mean value is close to the value re-

ported in Serbia and Montenegro, where it ranges between 22.44 and 103 mg/100 g (Bijelić et al. 2011; Jaćimović et al. 2015; Ognjanov et al. 2009), and it also resembles values recorded in Greece (14–103 mg/100 g; Pantelidis et al. 2007) and Turkey (11–106 mg/100 g; Aslantas et al. 2007; Copur et al. 2003; Pirlak et al. 2003).

The carbohydrate compounds measured in the 30 Austrian Cornelian cherry accessions were glucose and fructose with values ranging between 4.54 and 7.84 g/100 g and 2.86 and 5.44 g/100 g, respectively. These results are in agreement with results reported for Bulgaria (Petkova and Ognjanov 2018), Turkey (Okan et al. 2019), Russia (Perova et al. 2014), Poland (Antolak et al. 2017) and Montenegro (Martinović and Cavoski 2020) that oscillate between 1.90 and 3.8 g/100 g for fructose and between 2.5 and 12.26 g/100 g for glucose. Contrarily, the glucose and fructose values detected in this research are significantly lower than those from the Gemer Region of Slovakia (Brindza et al. 2009).

Glucose and fructose in Cornelian cherry have a crucial impact on producing drinks, sweets, syrup, marmalade as well as fresh fruit consumption because they determine the palatability of the fruits (Tural and Koca 2008; Turhan et al. 2007) but they might also influence—as for black carrot, elderberry and strawberry—the stability of anthocyanins (Sadilova et al. 2009).

The major anthocyanin compounds reported in *Cornus mas* are Cy 3-Gal and the Pg 3-Gal (Dinda et al. 2016). Our analyses revealed that cyanidin Cy 3-Gal values range between 0.063 and 2.886 mg/g and Pg 3-Gal between 0.064 and 2.355 mg/g. These findings are in line with previous studies published by other researchers (Kucharska et al. 2015; Pawłowska et al. 2010; Moldovan et al. 2016; Sozanski et al. 2014; Dzydzan et al. 2019). Although our maximum values are slightly higher than the aforementioned studies, they are lower than in the variety ‘Raciborski’ in

Poland (Szumny et al. 2015). Alongside anthocyanins, Cornelian cherries also contain the iridoids loganic acid and cornusides (Dinda et al. 2016; Szczepaniak et al. 2019). Iridoids are documented to be involved in plant defences against insects (Dyer et al. 1996; Richards et al. 2012), and iridoids isolated from *Cornus* species possess anti-inflammatory and antioxidative properties (Czerwińska and Melzig 2018).

The mean content for loganic acid and cornuside in our investigation was 12.364 mg/g and 0.709 mg/g, respectively, which places the Austrian accessions investigated closer to the range noted for some Polish varieties (Kucharska et al. 2015; Szczepaniak et al. 2019; Sozanski et al. 2014).

Flavonoids are the second largest constituents in fruits and major constituents of leaves of Cornelian cherry (Dinda et al. 2016). In our fruit analyses, Q 3-Glr content ranged between 0.115 and 0.331 mg/g, which is considerably lower than data reported from other regions (Pawłowska et al. 2010; Moldovan et al. 2016; Dzydzan et al. 2019). However, the values resemble data obtained in Serbia (4.45–151.82 µg/g) by Bajić-Ljubičić et al. 2018 and in Montenegro (13.40–29.66 mg/100) by Martinović and Cavoski (2020). The differences observed could be attributed primarily to the genotype of the plants as well as to the geographical location and the prevailing climatic conditions.

Quercetin has been classified as an antioxidant (Satyanarayana et al. 2001) and has been shown to prevent the nephrotoxic effect of cisplatin, without affecting its anti-tumour activity (Sanchez-Gonzalez et al. 2011). This flavonoid is also responsible for preserving hippocampal neurons and enhancing the synaptic plasticity (Akang et al. 2019).

Determining some principal bioactive compounds in *Cornus mas* accessions in Austria enabled the evaluation of their profile and compare it with those already described

Fig. 1 Percent of variability explained by 11 principal components (PCs)

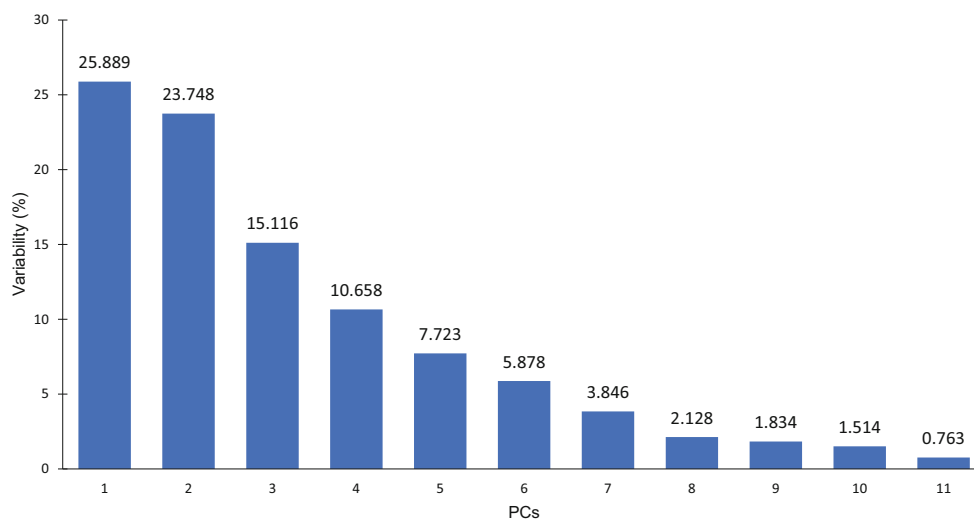


Table 4 Mean values for seven bioactive compounds determined in 30 accessions of Cornelian cherry from Austria

	Fructose g/100 g	Glucose g/100 g	Cy 3-Gal mg/g	Pg 3-Gal mg/g	Cornuside mg/g	Loganic acid mg/g	Q 3-Glr mg/g
Minimum	2.866	4.540	0.063	0.064	0.348	5.036	0.115
Maximum	5.439	7.845	2.886	2.355	1.345	21.654	0.331
Mean	4.086	5.966	0.798	0.923	0.709	12.364	0.167
Standard deviation	0.654	0.784	0.885	0.741	0.250	3.479	0.057

Cy 3-Gal cyanidin 3-*O*-galactoside, Pg 3-Gal pelargonidin-3-*O*-galactoside, Q 3-Glr quercetin-3-*O*-glucuronide

in other regions. This allowed us to evaluate the potential of the Austrian accessions as functional food as well as the importance of these results as part of breeding and selection programmes.

Principal Component Analysis

Principal component analysis produced 17 principal components (PCs) with eigenvalues greater than 0.6 (PC7), explaining 92.87% of the total variability observed (Fig. 1, shows 11 out of the 17 principal components; Table 4). Absolute values greater than 0.5 were found in the first seven most interesting PCs. Based on those criteria, the first seven PCs were taken into consideration (Table 5).

Principal component analyses showed that the first seven principal components (PC1-PC7) explain 25.9, 49.6, 64. 8, 75.4, 83.1, 89 and 92.87% of the variation, respectively (Table 5).

In the first component (PC1) the characteristics with higher scores are related to fruit weight, length and width as well as to flesh weight and account for 25.88% of the variability. This first component might be regarded as corresponding to the *fruit size*.

The second factor (PC2) correlated mainly with stone width and stone weight, flesh/stone ratio and % fruit flesh ($r = -0.860, -0.851, 0.874$ and 0.926 , respectively) and to a lesser extent with cornuside ($r = -0.499$) and has a contribution of 23.75% of the total variance. Therefore, it might be called the *stone dimensions, fruit flesh and cornuside* component.

Factor PC3 represents 15.11% variability associated with stone and fruit shape ($r = 0.853$) calculated from index fruit length/fruit width and index stone length/stone width along with stone length, which might be analysed as the *fruit shape* component.

Table 5 Correlations between variables and factors

Variables	PC1	PC2	PC3	PC4	PC5	PC6	PC7
Fruit weight (g)	0.969	0.062	-0.142	0.084	0.006	0.035	-0.032
Stone weight (g)	0.465	-0.851	-0.078	0.106	-0.133	-0.059	0.068
Flesh weight (g)	0.943	0.232	-0.136	0.069	0.032	0.049	-0.048
Flesh/stone ratio	0.361	0.874	0.001	-0.025	0.218	0.080	-0.096
Fruit length (mm)	0.813	0.065	0.430	0.263	-0.121	-0.097	0.061
Fruit width (mm)	0.878	-0.020	-0.286	0.286	0.129	-0.022	-0.009
Index (fruit length/fruit width)	-0.284	0.081	0.853	-0.102	-0.262	-0.076	0.065
Stone length (mm)	0.511	-0.420	0.621	0.133	-0.309	-0.129	0.102
Stone width (mm)	0.277	-0.860	-0.354	0.069	-0.143	-0.099	0.031
Index (stone length/stone width)	0.157	0.443	0.853	0.037	-0.075	-0.004	0.038
Fruit flesh (%)	0.297	0.926	-0.070	0.020	0.094	0.055	-0.097
Fructose	0.045	0.459	-0.304	0.345	-0.522	0.232	0.296
Glucose	-0.365	0.450	-0.374	0.246	-0.121	-0.190	0.545
Cornuside	-0.274	-0.499	0.152	0.406	0.359	0.468	0.032
Cyanidin 3- <i>O</i> -galactoside	-0.394	0.261	-0.181	0.699	-0.093	-0.285	-0.167
Loganic acid	0.017	-0.138	0.369	0.428	0.649	0.212	0.313
Quercetin-3- <i>O</i> -glucuronide	-0.235	-0.009	0.027	0.432	-0.480	0.598	-0.267
Pelargonidin-3- <i>O</i> -galactoside	-0.318	-0.025	0.126	0.711	0.134	-0.455	-0.248
Eigenvalue	4.660	4.275	2.721	1.918	1.390	1.058	0.692
Variability (%)	25.889	23.748	15.116	10.658	7.723	5.878	3.846
Cumulative %	25.889	49.636	64.752	75.410	83.133	89.012	92.857

Bold values indicate correlation coefficients with value greater than or equal to 0.5 in absolute value

Factor PC4 with 10.65% of total variability is a factor correlated with cyanidin 3-*O*-galactoside and pelargonidin-3-*O*-galactoside could be called an *anthocyanin* component.

Factors PC5, PC6 and PC7 represent 7.72, 5.9 and 3.85% of the total variance, respectively. The highest correlation for PC5 is *loganic acid* and *fructose* while for PC6 it is *quercetin-3-O-glucuronide* ($r=0.598$) and for PC7 it is *glucose*.

These principal components analyses indicate a substantial morphological variation between the accessions, which results in the decisive importance of morphological characterization in the evaluation of genetic diversity. Among the bioactive compounds considered the three most influential were cornuside, cyanidin 3-*O*-galactoside and pelargonidin-3-*O*-galactoside, as shown in PC2 and PC4. At this stage of understanding we believe that although the correlation between all groups of traits is not the same, all are represented in the first seven PCs, suggesting that these traits could be genetically related.

The accessions distribution on PC1 (*fruit size*) and PC2 (the component reflecting *stone dimensions, fruit flesh and cornuside*) are plotted in Fig. 2. The majority of accessions are located in the central part of the scatter plot defined by the oval. However, it is possible to assign accessions into main groups. The accessions located in the triangle share

a high fruit weight and high fruit length values. In addition, those accessions shared values ranging from high to medium by flesh weight and fruit width and the fruits have light red colour. Genotype 29 belonging to this group had the highest value for fruit flesh as well as for the flesh/stone ratio but had lower average cornuside values. A third group (rectangle) contains accessions that were chosen in this exploration for the light red colour (Laimer and Borroto, unpublished data) and at the same time they shared high fruit flesh (%) values.

In the lower part (23 and 6) and top left (4) of the figure, three outliers are found in which accession 6 had the lowest values for fruit weight, flesh weight and fruit width and together with 23 had the lowest values for flesh/stone ratio and fruit flesh. However, 23 had the highest cornuside, stone weight and stone width values, while 4 presented the lowest value in stone weight and low values for fruit weight and flesh weight, although the percentage fruit flesh is considered one of the highest in our study. As an interesting aside, accession 4 and 23 had red dark fruits, whereas 6 is a yellow genotype.

Based on the results in the present study, the observed accessions could be categorized as a representative natural population of *Cornus mas* in Lower Austria with a diverse morphological characteristic and a valuable source of

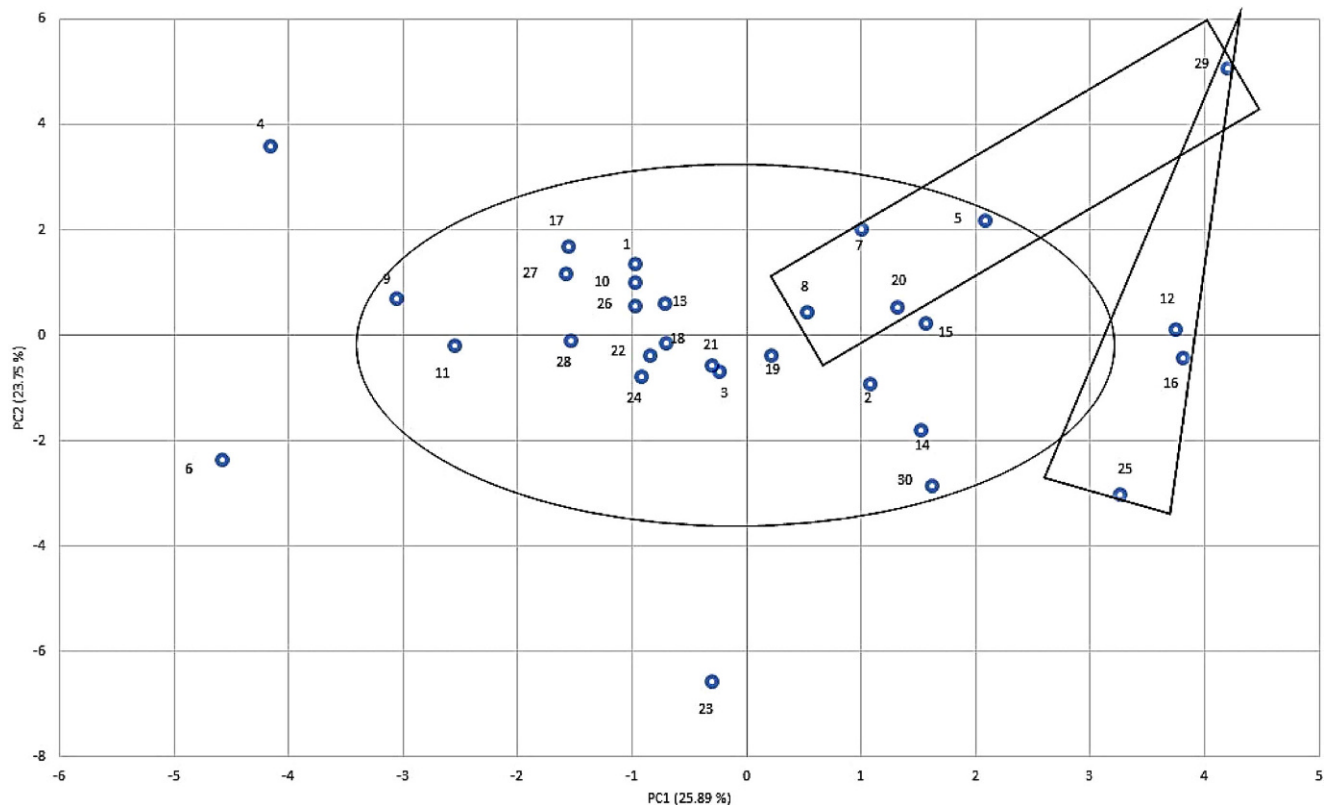


Fig. 2 Factor analysis plot of the first two factors showing the relationship between 30 Cornelian cherry Austrian accessions from Pielach Valley in Lower Austria

bioactive compounds; this is the first time that a phenotypic profile of Austrian Cornelian cherry fruits has been accomplished. As a result, a representative number of the accessions analysed were selected (Laimer et al. 2021) for the first in vitro Cornelian cherry germplasm collection in Austria due to its importance for the conservation of natural populations as well as for future breeding programmes.

Conclusion

This study highlights that *Cornus mas* accessions from Lower Austria, still neglected and underutilized, represent a natural population with diverse morphological characteristics and with potential as a beneficial source of bioactive compounds. It is the first time a phenotypic profile of Austrian Cornelian cherry fruits has been completed. Our findings will enable the selection of interesting genotypes in the development of a breeding strategy for genotypes adapted to future needs for a sustainable production in the region.

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Author Contribution M. Laimer and E.G. Borroto Fernández designed the experiments, carried out the analyses and wrote the paper. A. Mokhber and M. Zeiser assisted with the sampling and the analyses of the experiments.

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Declarations

Conflict of interest E.G. Borroto Fernández, A. Mokhber, M. Zeiser and M. Laimer declare that they have no competing interests.

Ethical standards For this article no studies with human participants or animals were performed by any of the authors. All studies mentioned were in accordance with the ethical standards indicated in each case.

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