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MORPHOLOGICAL FEATURES OF FRUITS OF VARIOUS SPECIES OF CHILLI PEPPERS

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The research focused on *Capsicum* spp. collection (*C. annuum* L., *C. baccatum* L., *C. chinense* Jacq.) cultivated under green-house conditions and examined in the term of morphological characteristics of quantitative (6) and qualitative (4) traits. Aim of the study was to determine the variability in the morphological fruit characters of 28 cultivars. The results revealed considerable morphological variability between average weight of fruits (0.32–25.94 g), weight of peduncle (0.01–0.41 g), weight of exocarp (0.24–24.60 g), weight of seed (0.04–2.14 g), weight of ovary (0.17–4.92 g) and number seeds per fruit (14.2–185.8 pieces). A cluster analysis was carried out, and a dendrogram was established. With quantitative variables, 6 groups were obtained. Correlations between morphological variables were also estimated. There were highly significant differences for most quantitative characters. The study showed that the weight of fruits parameters is correlated with the variables related to the weight of exocarp and weight of ovary. High diversity based on qualitative traits was detected for the shape of fruits, the colour of fruits ect. Obtained results confirmed that chilli peppers are suitable germplasm for their cultivation and distribution as ornamental plants, their potential uses and benefits to mankind cover many areas processing into food and nutrition, cosmetics, plant-based insecticides, pharmaceutical or medicine products.

Keywords: *Capsicum* spp., fruits, cultivars, morphometric characteristic

Introduction

Chilli pepper (*Capsicum* spp.) is a solaneceous plant, whose centre of origin in Middle America and Mexico is centre of genetic diversity and domestication. In the world, several hundred types of peppers are cultivated. The five major cultivated and economically most important species of *Capsicum* are *C. annuum* L., *C. chinense* Jacq., *C. frutescens* L., now widely cultivated throughout Europe, the southern United States, Africa, India, and China, and *C. baccatum* L. and *C. pubescens* Ruiz & Pav., cultivated predominantly in South America (Basu and De, 2003; Scaldaferro et al., 2018). The genus comprises approximately 42 described

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species (Barboza et al., 2019), with wide range of morphological variability, mainly in different shapes, sizes, colours and sensory attributes of its fruits (Nwachukwu et al., 2007; Barbosa et al., 2010; Ballina-Gómez et al., 2013; Wahua et al., 2014; Bicikliski et al., 2018).

Capsicum terminology is very confusing with pepper, chilli, chile, chilli, aji, paprika, and capsicum all used interchangeably to describe the plant (DeWitt and Bosland, 2009). Csillery (2006) indicates that the first component description of *Capsicum* was given in Hungarian herbal by Dioszegi and Fazekas (1807) cited by Bozokalfa et al., (2009). Chilli pepper is an important agricultural crop, not only because of its economic importance, but also for the nutritional value of its fruits (Aliu et al., 2017), mainly due to the fact that they are an excellent source of natural colours and antioxidant compounds (Rodríguez-Maturino et al., 2011; Medina-Juárez et al., 2012).

The *Capsicum* genus includes the sweet and hot chilli peppers, which have been popular from ancient times and at present are of great commercial interest, not only for the taste and colour of their fruits (Shaha et al., 2013), but also because of their essential oils and the presence of capsaicin (Pruthi, 2003; Nadi et al., 2020). Capsaicin is the pungent principle of hot chilli peppers, which are commonly used as spices and as medicines (Saleh et al., 2018), mainly applied topically to relieve neuropathic pain and itching (Papoui and Yosipovitch, 2010). The number of studies report that hot pepper seeds are rich in minerals content (Jarret et al., 2013; Zou et al., 2015). The content of vitamin C in the pepper fruit is higher than in Citrus (Finger et al., 2010). The pepper fruit is a rich source of vitamin A, E, C and P in green chilli (Howard et al., 2000; Marin et al., 2004). They have a high level of vitamins C and E as well as the total of antioxidants is completed by phenolic compounds, which occur in peppers in connection with sugars (Shotorbani and Jamei, 2013; Batiha et al., 2020).

Preservation of such plant genetic resources is extremely important for plant breeding as well as for society as a whole (Moreira et al., 2018). In view of the cultural and economic importance of the *Capsicum*, the development of new and improved cultivars carrying characteristics that meet the needs of farmers and the consumers is primordial. To achieve this goal, plant breeders are dependent on plant genetic resources and need access to the widest genetic diversity available. For these reasons, the preservation of wild species, local varieties and traditional genotypes in collections or germplasm banks is very important (Nass et al., 2012). In addition, the characterization of these materials is essential information for the conservation and use in plant breeding programs (Murillo-Amador et al., 2015; Sarobo, 2019).

Variability study of agro-morphological characteristics of various *Capsicum* species in conditions of Botanical Garden (Slovakia) due to biodiversity conservation and plant breeding program was aim of our examination.

Material and methodology

Biological material

We experimentally studied 28 cultivars of peppers from the three *Capsicum* species (*C. annuum*, *C. baccatum* and *C. chinense*) (Table 1). All 28 cultivars of chilli peppers that were the subject of the study were grown under green-house conditions in the Botanical Garden, which is located on the area of the Slovak University of Agriculture in Nitra.

Table 1 List of 28 cultivars of *Capsicum* spp.

No.	**Species**	**Cultivars**
1	*Capsicum annuum* L.	Black Kobra
2	*Capsicum annuum* L.	Chocho
3	*Capsicum annuum* L.	Jalapeno
4	*Capsicum annuum* L.	Kilian
5	*Capsicum annuum* L.	Medusa
6	*Capsicum annuum* L.	Pepperoncini Greek
7	*Capsicum annuum* L.	Tabasco
8	*Capsicum annuum* L.	Trinidad Hot Cherry
9	*Capsicum annuum* var. *nigrum*	Black Prince
10	*Capsicum baccatum* L.	Aji Amarilo
11	*Capsicum baccatum* L.	Aji fantasy sparkly white
12	*Capsicum baccatum* L.	Aji Rojo
13	*Capsicum baccatum* L.	Bishops Crown Red
14	*Capsicum baccatum* L.	El Oro De Ecuador
15	*Capsicum baccatum* L. var. *pendulum*	Escabeche
16	*Capsicum chinense* Jacq.	Aji Charapita
17	*Capsicum chinense* Jacq.	Carolina Reaper
18	*Capsicum chinense* Jacq.	Citron
19	*Capsicum chinense* Jacq.	Fatali Red
20	*Capsicum chinense* Jacq.	Fidalgo Roxa
21	*Capsicum chinense* Jacq.	Habanero Chocolate
22	*Capsicum chinense* Jacq.	Habanero Peach
23	*Capsicum chinense* Jacq.	Haba nero Red
24	*Capsicum chinense* Jacq.	Habanero Red Savina
25	*Capsicum chinense* Jacq.	Jolokia White
26	*Capsicum chinense* Jacq.	Peter´s Orange
27	*Capsicum chinense* Jacq.	Pimenta De Neyde
28	*Capsicum chinense* Jacq.	Trinidad Scorpion Peach

Morphometrical analysis

The following quantitative and qualitative properties were evaluated by morphometrical analysis:

a) fruit weight (g); stem weight (g); weight of exocarp (g); ovary weight (g); seed weight (g); number of seeds in fruit (pcs);
b) shape of fruits; fruit shape at peduncle; fruit shape at blossom end; colour of the fruits.

The weights were evaluated by analytical balance (Kern ADB-A01S05, Germany), accurate to 0.01 g.

Statistical analysis

It was evaluated the variability of the test files in each character using descriptive statistics. For the characteristics of the files, it was used the basic descriptors of variability: average, minimum measured value, maximum measured value, the coefficient of variation (%). The degree of variability was determined by the coefficient of variation values. The given parameter is independent of the unit of the evaluated character. Theoretically, they can acquire different values (Stehlíková, 1998). Cluster dendrogram were performed in the free software for scientific data analysis PAST 2.17. We used correlation analysis in the program STATISTICA 1.10 to determine the dependence between individual characters.

Results and discussion

The researched morphological diversity among pepper populations is helpful for breeding programs aimed in selecting superior genotypes. Local or introduced pepper populations is included in broader genetic analyses and considered as a source of new genetic variability used for the development of inbred lines in breeding program.

The evaluation of plant genetic resources has been considered of prime importance, especially in those species having economic importance (Dibuz et al., 1998; Grygorieva et al., 2014, 2017, 2018a, b; Monka et al., 2014; Lima et al., 2017; Ivanišová et al., 2017; Vinogradova et al., 2017; Fatrcová-Šramková et al., 2019; Brindza et al., 2019).

The weight of fruits of chilli pepper cultivars is presented in Table 2. In the evaluated collection was determined the average weight of fruits in the range from 0.318 g (Aji Charapita) to 25.94 g (Trinidad Hot Cherry). For the complete, we determined the weight of fruits up to 10 g for 18 cultivars, from 10.1 to 20 g for 7 cultivars, and the weight of fruits above 20 g for 3 cultivars. The values of the coefficient of variation were in the interval 9.166–42,020%, which documented low up to high degree of variability of the character within the collection.

In agreement with our description, similar fruit weight was found by Bianchi et al., (2020) for *C. chinense* from four Brazilian region and one from Peru (1.04–18.61 g), for cultivated species from West Africa *C. annuum* (5.14 ±0.42–20.97 ±2.69) and *C. frutescens* (1.83 ±0.25) by Olatunji and Afolayan (2019). Jarret and Berke (2008) characterized *C. chinense* from USDA/ARS *Capsicum* germplasm collection and determined mean fruit weight in a range of 0.18 to 22.7 g.

Table 2 presents the weights of peduncle, which were determined as the average values in the range from 0.017 g (Black Prince) to 0.410 g (Trinidad Hot Cherry). For the complete, we determined the weight of peduncles to 0.10 g for 16 cultivars, from 0.10 to 0.20 g for 8 cultivars, and the peduncle weights above 0.20 g and up for 4 cultivars. The values of coefficients of variation document a medium up to high degree of variability.

Table 2 Statistical characteristics of variability of fruits in the collection of chilli pepper genotypes

Cultivars	Fruit weight (g)				Peduncle weight (g)			
	min	max	$\bar{x}$	V (%)	min	max	$\bar{x}$	V (%)
Habanero Red	7.95	11.95	9,76	17.21	0.07	0.17	0.12	34.48
Peter´S Orange	12.65	17.81	14.66	15.40	0.27	0.41	0.33	19.24
Tr. Hot Cherry	21.48	29.98	25.94	12.88	0.04	0.78	0.41	68.96
Kilian	1.43	3.51	2.32	32.38	0.01	0.06	0.02	74.06
Tabasco	1.02	2.23	1.79	27.28	0.11	0.30	0.18	42.53
Escabeche	4.86	8.05	7.05	18.63	0.03	0.06	0.04	24.69
Pepper. Greek	4.71	11.36	6.53	42.02	0.03	0.13	0.09	38.69
Fidalgo Roxa	3.39	5.30	3.89	20.80	0.01	0.14	0.05	96.55
Jalapeno	11.43	20.92	15.67	22.09	0.09	0.13	0.12	15.00
Fatali Red	5.69	7.32	6.66	12.39	0.06	0.07	0.07	3.89
Black Kobra	3.08	4.70	3.73	18.97	0.02	0.07	0.05	41.53
Aji Rojo	16.71	27.87	23.18	19.48	0.23	0.42	0.32	22.93
Carolina Reaper	5.61	8.25	6.67	16.39	0.04	0.06	0.04	19.44
Tr. Scorp. Peach	4.95	8.52	6.74	18.90	0.02	0.04	0.03	22.02
Aji Charapita	0.26	0.44	0.32	22.49	0.01	0.14	0.05	100.54
Bishops Cr. Red	15.90	26.87	22.60	20.11	0.07	0.16	0.10	38.74
Black Prince	0.62	1.02	0.87	17.92	0.01	0.02	0.01	18.10
El Oro De Ecuador	3.93	8.08	6.08	25.66	0.07	0.17	0.12	33.54
Chocho	9.52	22.08	14.29	37.17	0.27	0.45	0.38	20.44
Habanero Peach	11.14	16.83	14.37	17.66	0.04	0.15	0.11	37.69
Medusa	1.72	2.28	2.10	10.67	0.07	0.08	0.07	7.20
Jolokia White	6.69	8.66	7.75	9.77	0.06	0.08	0.07	17.20
Habanero Chocolate	12.31	19.28	15.39	18.85	0.03	0.08	0.06	28.69
Pimenta De Neyde	3.81	5.55	4.72	15.75	0.03	0.06	0.05	25.17
Habanero Red S.	7.49	13.35	10.50	26.19	0.03	0.10	0.06	41.13
Citron	2.08	2.63	2.30	9.16	0.04	0.07	0.05	21.30
Aji Amarilo	4.08	6.53	5.42	17.49	0.08	0.15	0.11	24.77
Aji F. Sparkly W.	10.20	14.70	12.40	14.27	0.15	0.18	0.17	7.22

Note: *n* – the number of measurements; min, max – minimal and maximal measured values; $\bar{x}$ – arithmetic mean; V – coefficient of variation (%)

The exocarp weight of the evaluated chilli pepper cultivars is presented in Table 3. It was determined the average exocarp weight in the range from 0.244 g (Aji Charapita) to 24.601 g (Trinidad Hot Cherry). For the complete, we determined the weight of exocarp up to 10 g in 20 cultivars, from 10.1 to 20 g in 5 cultivars and the weight of the exocarp from above 20 g upwards in 3 cultivars. The values of coefficients of variation document a medium up to high degree of variability.

Table 3 Statistical characteristics of variability of exocarp weight and number of seeds per fruit in the collection of chilli pepper genotypes

Cultivar	Number Of Seeds Per Fruit (Pcs)				Number Of Seeds Per Fruit (Pcs)			
	min	max	$\bar{x}$	V (%)	min	max	$\bar{x}$	V (%)
Habanero Red	7.85	11.69	9.62	16.86	35	57	43.80	20.06
Peter´s Orange	12.33	17.41	14.31	15.65	55	86	67.20	18.98
Tr. Hot Cherry	20.50	28.33	24.60	12.67	158	243	185.80	18.34
Kilian	0.99	2.71	1.76	34.60	18	49	35.40	39.07
Tabasco	0.89	2.00	1.58	28.09	20	72	46.60	47.44
Escabeche	3.62	7.19	5.55	23.84	2	52	43.60	27.36
Pepper. Greek	3.99	10.62	5.76	47.73	116	170	139.60	16.75
Fidalgo Roxa	3.16	5.10	3.70	21.72	10	40	23.00	52.17
Jalapeno	11.20	20.57	15.38	22.22	37	106	74.80	33.14
Fatali Red	5.46	7.05	6.44	12.77	12	41	26.00	47.73
Black Kobra	2.70	4.24	3.33	20.22	46	72	60.40	18.68
Aji Rojo	15.49	25.94	21.70	19.31	52	139	100.20	33.81
Carolina Reaper	4.96	7.53	6.02	17.56	14	44	28.00	44.67
Tr. Scorp. Peach	4.81	8.32	6.58	19.01	4	23	14.20	62.07
Aji Charapita	0.22	0.27	0.24	8.49	15	17	16.00	6.25
Bishops Cr. Red	13.49	25.45	20.69	25.31	34	136	81.40	44.72
Black Prince	0.52	0.88	0.76	18.86	15	41	31.80	33.23
El Oro De Ecuador	3.85	7.80	5.94	25.30	6	37	27.20	46.16
Chocho	2.00	15.54	9.14	53.44	75	166	115.40	35.91
Habanero Peach	11.00	16.61	14.22	17.61	43	76	52.60	26.19
Medusa	1.14	1.62	1.43	12.77	38	78	60.80	24.76
Jolokia White	6.60	8.56	7.64	9.88	16	56	28.20	57.85
Habanero Chocolate	12.01	18.88	15.05	18.95	38	76	59.20	23.47
Pimenta De Neyde	2.89	4.73	3.87	18.94	19	64	39.20	42.12
Habanero Red S.	6.90	12.24	9.66	26.39	25	63	37.20	43.36
Citron	1.50	2.00	1.74	13.09	36	47	39.60	10.94
Aji Amarilo	4.00	6.37	5.31	17.30	30	131	91.20	40.64
Aji F. Sparkly White	10.05	14.48	12.17	14.20	25	102	70.60	41.01

Note: *n* – the number of measurements; min, max – minimal and maximal measured values; $\bar{x}$ – arithmetic mean; V – coefficient of variation (%)

Table 3 presents the number of seeds per fruit. We determined the average number of seeds in the range from 14.2 pieces (Trinidad Scorpion Peach) to 185.8 pieces (Trinidad Hot Cherry). For the complete, we determined the number of seeds up to 50 pieces for 13 cultivars, from 51 to 100 pieces for 9 cultivars and the number of seeds over 100 pieces for 4 cultivars. The values of the coefficients of variation document a medium up to high degree of variability. Comparison our values with other authors showed similar results, e.g. by Zhigila et al. (2013) seeds per fruit were determined in five varieties *C. annuum* L. in Nigeria (39–44 and 97–122 pcs), Carvalho et al. (2017) studied Brazilian *C. frutescens* L. fruit features and determined seeds below 20 pcs per fruit.

The ovary weight of the evaluated chilli pepper cultivars is presented in Table 4. We determined the average ovary weight in the range from 0.174 g (Aji Charapita) to 4.920 g (Trinidad Hot Cherry). For the complete, we determined the ovary weight up to 1 g for 16 cultivars, from 1.1 to 2 g for 5 cultivars and the ovary weight over 2 g for 7 cultivars. The values of coefficients of variation document a medium up to high degree of variability.

Table 4 presents the seed weight. We determined the average seed weight in the range from 0.046 g (Aji Charapita) to 2.146 g (Chocho). For the complete, we determined the seed weight up to 1 g for 24 cultivars, from 1 to 2 g for 3 cultivars and the seed weight above 2 g for 1 cultivar. The values of coefficients of variation document a medium up to high degree of variability.

Dias et al. (2013) studied weight of 1000 seeds (g) for *C. chinense* (6.57 g), *C. annuum* (5.18 g), *C. baccatum* (5.91 g) and *C. frutescens* (4.29 g) in Brazil. Nsabiyera et al. (2012) characterized weight of 300 seeds *C. annuum* of 10 local (1.5 g) and 27 exotic introduced genotypes (1. g) in Uganda regions. Results from West Africa by Olatunji and Afolayan (2019) showed for two cultivated species *C. annuum* and *C. frutescens* number of seeds per fruit values 18.70 ±2.54–118.50 ±14.91 and 24.10 ±2.20, respectively.

For a more complex assessment of the issue was determined the linear dependence between the weight of fruit and weight of exocarp and other traits. In both evaluated variants was determined a positive statistically high dependence between fruit weight and exocarp weight, with one exception. A similar dependence was also found between exocarp weight and ovary weight, with few exceptions. The correlation linear dependence between some features of the evaluated chilli pepper cultivars is presented in Table 5.

Table 4 Statistical characteristics of variability of ovary weight and seed weight in the collection of chilli pepper genotypes

Cultivar	Ovary weight (g)				Seed weight (g)			
	min	max	$\bar{x}$	V (%)	min	max	$\bar{x}$	V (%)
Habanero Red	0.80	1.23	0.99	17.65	0.27	0.42	0.36	16.78
Peter´s Orange	1.12	1.68	1.32	17.44	0.55	0.85	0.67	18.75
Tr. Hot Cherry	4.15	5.77	4.92	14.15	1.60	1.91	1.75	8.61
Kilian	0.31	0.58	0.45	25.13	0.15	0.38	0.25	39.30
Tabasco	0.28	0.84	0.62	37.34	0.13	0.57	0.33	52.16
Escabeche	0.50	0.81	0.66	18.65	0.19	0.40	0.33	25.51
Pepper. Greek	1.61	2.01	1.84	10.05	0.94	1.09	1.02	6.16
Fidalgo Roxa	0.35	0.71	0.49	29.98	0.06	0.28	0.13	62.93
Jalapeno	1.42	3.71	2.21	39.64	0.45	1.45	0.82	46.90
Fatali Red	0.57	3.04	1.69	69.34	0.11	0.36	0.22	42.83
Black Kobra	0.65	1.14	0.90	20.08	0.23	0.61	0.42	34.10
Aji Rojo	1.48	3.83	2.58	33.62	0.58	1.55	1.04	34.30
Carolina Reaper	0.28	0.94	0.55	45.01	0.13	0.54	0.30	49.91
Tr. Scorp. Peach	0.26	1.05	0.57	52.28	0.01	0.58	0.19	119.65
Aji Charapita	0.05	0.60	0.17	137.30	0.04	0.05	0.04	11.90
Bishops Cr. Red	1.56	3.31	2.31	28.11	0.42	1.41	0.85	41.72
Black Prince	0.12	0.30	0.22	27.71	0.07	0.17	0.14	25.46
El Oro De Ecuador	0.21	0.72	0.54	36.65	0.06	0.38	0.27	45.11
Chocho	1.82	3.62	2.74	31.58	0.85	5.74	2.14	95.90
Habanero Peach	1.38	2.71	2.25	22.84	0.43	0.70	0.51	22.12
Medusa	0.23	0.41	0.35	20.42	0.17	0.29	0.24	18.40
Jolokia White	0.72	3.58	1.99	70.45	0.12	0.47	0.23	60.31
Habanero Chocolate	1.71	3.14	2.15	27.23	0.48	0.93	0.75	22.98
Pimenta De Neyde	0.44	0.76	0.61	18.47	0.16	0.32	0.27	23.23
Habanero Red S.	0.53	1.20	0.77	39.48	0.22	0.54	0.32	41.70
Citron	0.54	0.62	0.56	6.18	0.33	0.42	0.36	9.86
Aji Amarilo	0.38	1.24	0.85	36.76	0.24	0.95	0.64	40.06
Aji F. Sparkly White	1.21	2.16	1.54	24.11	0.21	0.81	0.53	40.57

Note: n – the number of measurements; min, max – minimal and maximal measured values; $\bar{x}$ – arithmetic mean; V – coefficient of variation (%).

Table 5 Correlation linear dependence between fruit traits

Cultivar	Fruit weight (g)					Exocarp weight (g)				
	WEX	WOV	WSE	THF	NSF	WOV	WSE	THF	NSF	LEF
Habanero Red	0.999	0.548*	0.461	0.110	0.019	0.562	0.477	0.099	0.039	0.953**
Peter´S Orange	0.999	0.553*	0.397	0.734*	0.472	0.546	0.386	0.726*	0.458	0.652*
Tr. Hot Cherry	0.999	0.805**	0.934**	0.555	0.508	0.811**	0.943**	0.544	0.523	0.787*
Kilian	0.996**	0.750*	0.637*	0.912**	0.651*	0.723*	0.587	0.910**	0.607*	0.584
Tabasco	0.989**	-0.012	0.203	-0.564	0.068	-0.096	0.157	-0.595	0.007	0.488
Escabeche	0.927**	0.921	0.864**	0.783*	0.842**	0.977**	0.832**	0.835**	0.781*	0.735*
Pepper. Greek	0.995**	0.401	-0.083	0.952**	-0.197	0.450	-0.009	0.962**	-0.118	-0.834
Fidalgo Roxa	0.999**	0.746*	0.874**	0.575	0.663*	0.714*	0.855**	0.580	0.628	-0.618
Jalapeno	0.999	0.956**	0.879**	0.044	0.947**	0.956**	0.880**	0.049	0.946**	-0.271
Fatali Red	0.999	0.775*	0.783*	0.662*	0.759*	0.793*	0.795*	0.668	0.777*	0.947**
Black Kobra	0.999**	0.730*	-0.164	0.929**	0.515	0.753*	-0.134	0.927**	0.548	0.510
Aji Rojo	0.996**	0.924**	0.422	-0.468	0.619*	0.933**	0.405	-0.444	0.597	0.949**
Carolina Reaper	0.997**	0.974**	0.923**	0.361	0.869**	0.978**	0.918**	0.384	0.847**	0.079
Tr. Scorp. Peach	0.999	0.435	-0.766	0.353	-0.553	0.428	-0.769*	0.347	-0.552	0.728*
Aji Charapita	0.020	-0.079	0.249	-0.063	-0.489	0.374	-0.924**	0.066	0.241	-0.358
Bishops Cr. Red	0.958**	0.649*	0.545	0.558	0.616*	0.798*	0.710*	0.683	0.748*	0.681*
Black Prince	0.996**	0.630*	0.865**	0.918**	0.691*	0.693	0.896**	0.894**	0.746*	0.757*
El Oro De Ecuador	0.999**	0.761*	0.775*	0.800**	0.894**	0.766*	0.787*	0.779*	0.905**	0.854**
Chocho	-0.339	0.520	0.365	0.889**	0.258	0.331	0.741*	-0.537	0.546	0.216
Habanero Peach	0.999	0.093	0.726*	0.585	0.733*	0.095	0.713*	0.601	0.720*	0.459
Medusa	0.977**	0.931**	0.813**	0.106	0.794*	0.841**	0.716*	0.290	0.683*	0.344
Jolokia White	0.999	0.662*	0.300	-0.097	0.323	0.658	0.289	-0.097	0.313	0.313

Continuation of table 5

Cultivar	Fruit weight (g)					Exocarp weight (g)				
	WEX	WOV	WSE	THF	NSF	WOV	WSE	THF	NSF	LEF
Habanero Chocolate	0.999	0.859**	0.529	0.902**	0.526	0.857**	0.522	0.900**	0.520	-0.309
Pimenta De Neyde	0.983**	0.421	0.097	0.643	-0.229	0.250	-0.082	0.694	-0.346	0.597
Habanero Red S.	0.996**	0.638*	0.655	-0.133	0.606	0.564	0.590	-0.080	0.535	0.511
Citron	0.759*	0.683*	0.876**	-0.910**	0.874**	0.181	0.389	-0.789*	0.580	0.694*
Aji Amarilo	0.999	0.981**	0.958**	0.497	0.891**	0.981**	0.959**	0.506	0.893**	0.779*
Aji F. Sparkly W.	0.999	0.738*	0.693*	-0.043	0.694	0.754*	0.701*	-0.023	0.697*	0.798*

Note: WEX – weight of exocarp; WOV – weight of ovary; WSE – weight of seed; THF – thickness of flesh; NSF – number seeds per fruit; LEF – length of fruit; **– correlation is significant at the 0.01 level; * – correlation is significant at the 0.05 level

Shape and colour of fruits

In Figure 1 we present the shape and colour of the fruits of the evaluated chilli pepper cultivars. The comparison shows a significant variability of both traits and extreme differences between cultivars, which are also important distinguishing features of individual varieties. The shape of fruits is characterized as campanulate, blocky, ovoid, round, almost round, linear, triangular, rectangular, elongate etc. Fruit shapes at peduncle attachment were described as lobate, cordate or truncate, fruit shapes at blossom end were described as sunken or pointed (Figure 1). The colour of the fruit can also be misleading, as each variety has a different length of vegetative period and sometimes varieties with a longer vegetative period do not have enough time to reach full technological maturity. Mature fruit colours included red, orange, yellow, brown (chocolate), and cream. In many cases the colouring of fruits with the presence of natural dyes in the flesh also determines the fruit antioxidant activity (Rodríguez-Maturino et al., 2011; Medina-Juárez et al., 2012).

Figure 1 Shape and colour of fruits of evaluated cultivars of chilli pepper (Photo: V. Horčinová Sedláčková, A. Oravec, 2018)

Figure 2 presents a longitudinal section of the fruits of chilli pepper cultivars, in which the number of seeds per fruit was evaluated. The comparison shows significant variability in the given trait and large differences between cultivars. The number of seeds per fruit has a significant effect on the multiplications of individual cultivars.

Figure 3 presents a cross-section of the fruits of the evaluated cultivars of chilli pepper, in which we evaluated the width of the fruit and the thickness of the flesh. The comparison shows a relatively high variability in both features. The fruit width and the flesh thickness determine the total weight of the fruit and thus the amount of dry matter in the fruit.

Figure 2 Comparison of evaluated cultivars of chilli pepper in longitudinal section of fruits (Photo: V. Horčinová Sedláčková, A. Oravec, 2018)

Figure 3 Comparison of the evaluated cultivars of chilli pepper in the cross section of the fruit (Photo: V. Horčinová Sedláčková, A. Oravec, 2018)

Examine of variability for fruit-related traits to select the suitable genetic material has been also shown in other *Capsicum* spp. studies (Carvalho et al., 2017; Bicikliski et al., 2018; Olatunji and Afolayan, 2019; Bianchi et al., 2020). Genetic diversity of characters of chilli peppers based on phenotypic and molecular descriptors have been studied by several authors (Bozokalfa et al., 2009; Dias et al., 2013; Moreira et al., 2018). However, most of them focused in morphological descriptors of fruit and fewer ones have examined a broad range of morpho-agronomic descriptors including both qualitative and quantitative traits (Orobiyi et al., 2018; Andrade et al., 2020; Bianchi et al., 2020).

The documentation obtained from the evaluation of chilli pepper fruits confirms the significant variability of qualitative as well as quantitative features. Results from the correlation analysis (Table 5) and the cluster analysis (Figure 4) confirm the statistically significant differences between the cultivars.

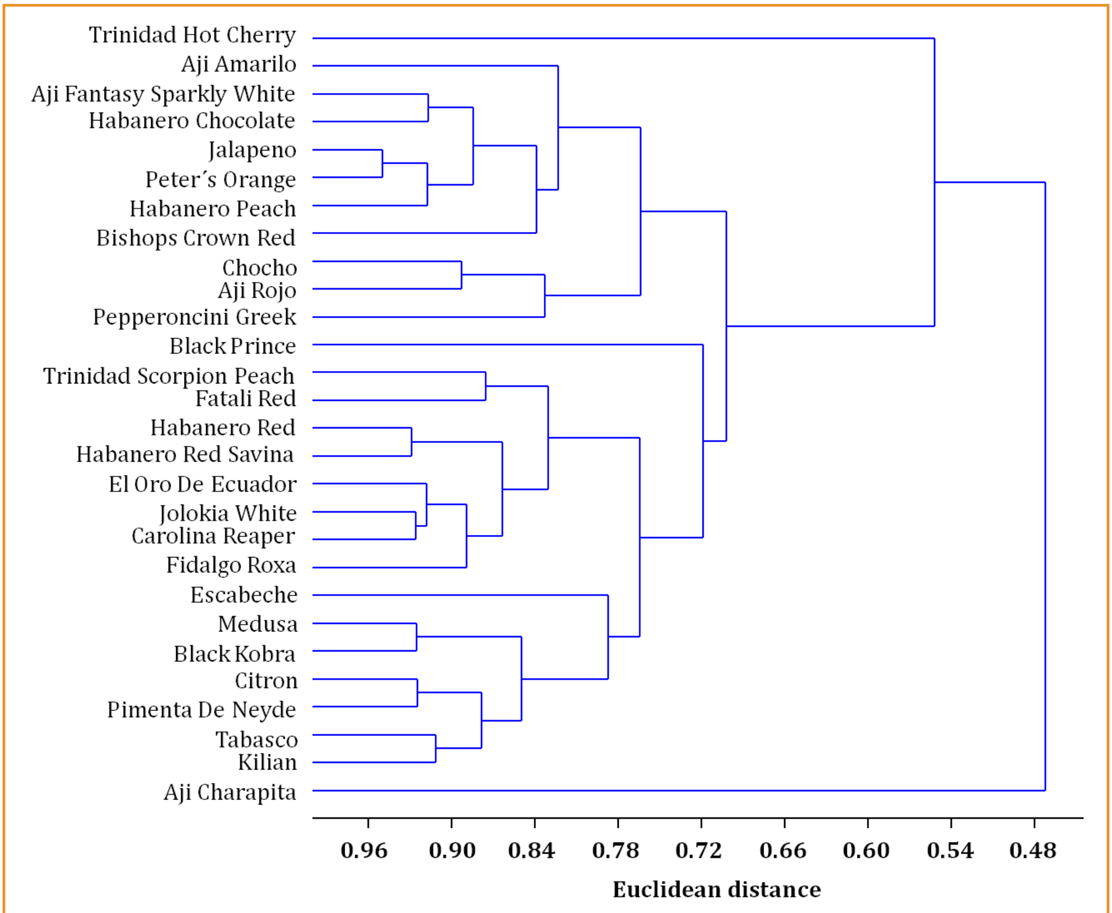

Figure 4 Dendrogram of 28 cultivars of chilli peppers based on morphometric characteristics of fruits

The information gathered from cluster analysis are useful to identify genetic variability among plants. Clustering of genotypes signifies close genetic affinity between/among species and can be used in resolving taxonomic complexities (Olatunji and Afolayan, 2019).

The result from the cluster analysis indicated that there was considerable variability among the cultivars of three *Capsicum* species which allowed them to be separated into distinct groups (Figure 4). The cluster analysis from 6 quantitative morphological traits examined that *Capsicum* spp. cultivars were divided into six clusters. Cluster II, IV and cluster V contained the largest number of genotypes. Cluster I (Trinidad Hot Cherry with the highest mean values) and cluster III (Black Prince) and Cluster VI (Aji Charapita with the lowest mean values) contained only cultivar, which differ from other genotypes of collection by all parameters.

Many other authors have used cluster analysis to study morphological characters of chilli peppers (Nsabiyera et al., 2013; Orobiyi et al., 2018; Olatunji and Afolayan, 2019; Andrade et al., 2020). Based on the distance between species of different clusters, contrasting parents may be identified and used in hybridization program for generating wider variability for selection and crop improvement (Sarobo, 2019).

Conclusions

Our results clearly confirmed statistically significant differences between the evaluated pepper cultivars in all examined traits. The results contribute to the expansion of theoretical and practical knowledge about some basic morphometric and production characteristics of chilli pepper fruits in the conditions of Slovakia. Many tested cultivars of chilli peppers are promising for their cultivation, distribution as ornamental plants and processing into food products, especially for small, young and family farms, which can significantly contribute to their socio-economic development and environmental improvement.

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