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Morpho-agronomic characterization and genetic divergence in lentil genotypes

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ABSTRACT

Lentil production has been increasing in Brazil, due to strong national and international demand. Despite the economic importance, few cultivars are available on the Brazilian market. The aim of this study was to evaluate 48 lentil inbred lines and one commercial cultivar (Silvina), based on morpho-agronomic traits and to identify genotypes which can be used in a plant breeding program. Twenty-one morpho-agronomic descriptors (nine qualitative and twelve quantitative) were used. The descriptors showed genetic variability among the genotypes. Clustering techniques using characterization data allowed to identify genetically divergent genotypes as well as identify superior genotypes in relation to agronomic traits: FLIP2010-8L and FLIP2010-12L (similarity group I), FLIP2010-99L, FLIP2010-20L and FLIP2010-106L (group II), FLIP90-25L and 6031 (group III), FLIP2007-16L (group IV) and the commercial cultivar Silvina (group V). We concluded that these genotypes have the potential to be used in lentil breeding programs.

Keywords: *Lens culinaris*, genetic resources, genetic variability, productivity.

RESUMO

Caracterização morfoagronômica e divergência genética em genótipos de lentilha

A produção de lentilha apresenta tendência de crescimento no Brasil devido a uma forte demanda do mercado nacional e internacional por esta hortaliça leguminosa. Apesar da importância econômica, existem poucas cultivares disponíveis no mercado brasileiro. O objetivo deste estudo foi avaliar 48 linhagens de lentilha e uma cultivar comercial (Silvina), com base em características morfoagronômicas, e identificar genótipos que possam ser empregados no melhoramento genético. Foram utilizados 21 descritores morfoagronômicos (nove qualitativos e doze quantitativos) que evidenciaram a existência de variabilidade genética entre os genótipos estudados. A associação das técnicas de agrupamento com os dados de caracterização possibilitou a identificação de genótipos geneticamente divergentes e, ao mesmo tempo, superiores quanto a características agronômicas: FLIP2010-8L e FLIP2010-12L (grupo de similaridade I), FLIP2010-99L, FLIP2010-20L e FLIP2010-106L (grupo II), FLIP90-25L e 6031 (grupo III), FLIP2007-16L (grupo IV) e a cultivar comercial Silvina (grupo V). Esses genótipos apresentam potencial para serem utilizados em programas de melhoramento genético da espécie.

Palavras-chave: *Lens culinaris*, recursos genéticos, variabilidade genética, produtividade.

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Lentil (*Lens culinaris*) belongs to *Fabaceae* family. This crop is of great importance for global economy, and it stands out for its nutritional value and food safety issues for millions of people around the world, especially in under-developed countries (Rawal & Bansal, 2019). The grains are nutritive, rich in proteins, carbohydrates, micronutrients, vitamins and aminoacids, lysine and tryptophan (Shahwar *et al.*, 2017). The commercial use of lentils includes whole grain, split, peeled or processed as flour. The plant can fix atmospheric nitrogen in association with *Rhizobium sp.* (Rasheed *et al.*, 2020), and the cultivation is a good possibility for crop rotation or succession, since lentil benefits, directly, soil fertility (Liu *et al.*, 2019). Besides, the plant shows climatic adaptability (Strydhorst *et al.*, 2015), which makes it widely distributed around the world.

Nowadays, Canada is the largest producer and exporter of lentil, 32.8% of total global production. Although India is the country with the largest cultivated area, about 25.4% of world production (Faostat, 2020), the country has low average crop productivity (731 kg ha^{-1}) comparing with the average productivity worldwide (1.041 kg ha^{-1}) (Faostat, 2020). This low productivity leads the Indian country to frequent imports of green and red lentils in order to meet its own demand. Brazilian lentil production is still negligible and domestic demand is supplied by imports, mainly from Canada, Argentina and The United States. In 2020, Brazil imported about 21 thousand tons, which means about US$ 13.3 millions on lentil import (Comex Stat, 2021).

In Brazil, mainly in Midwest region, lentil is an excellent option

for drip-irrigated crop during winter, reaching average productivities of 1.200 to 1.600 kg ha^{-1} in experimental conditions (Giordano & Nascimento, 2009). Sowing can be performed in April or May, and optimal temperatures for germination and development of the crop are 18 and 24ºC, respectively (Vieira & Lima, 2016). Thus, due to the productive potential verified, favorable climatic conditions and to an increasing demand of national and international market, mainly the Indian markets, Brazilian agribusiness is able to consolidate its production.

Although few lentil breeding studies have been carried out in Brazil in 1999, cultivar Silvina was released (Embrapa Hortaliças, 2014) for green lentil production, big seed (type macrosperm) and yellow cotyledon, the preferred type among Brazilian consumers (Vieira *et al*., 2001). Worldwide, small-seed red lentils (microsperm type) and orange cotyledon are the most produced and commercialized worldwide, due to the international market demand, mainly from the Indian subcontinent (Rawal & Bansal, 2019). However, this type of lentil has not been produced in Brazil yet.

International Center for Agricultural Research in the Dry Areas (ICARDA), holder of the largest collection of lentils in the world (Kumar *et al*., 2013), made available to Embrapa Hortaliças genotypes of macro and microsperm types, in order to expand the genetic basis and resume the breeding program for this species in Brazil. However, information about these genotypes are unavailable, and studies on morphological and agronomical characterization are necessary. These studies can contribute for the breeding program, identifying genotypes which present precocity, high yield, grain characteristics that meet the requirements of traders and consumers, adaptation to mechanized harvest and other agronomic traits of interest (Malhotra *et al.*, 2019).

Studies on characterization and evaluation performed through observations (qualitative traits) and measurements (quantitative traits) using morphological descriptors are able to provide the first genetic variability estimates in the germplasm (Burle & Oliveira, 2010), forming an important data basis which can subsidize genetic breeding for different purposes. Besides, using multivariate analysis techniques, based on dissimilarity measures, make it possible to evaluate, simultaneously in relation to several traits, the genetic divergence among the genotypes.

This study aimed to evaluate a set of lentil genotypes provided by ICARDA based on morpho-agronomic traits to identify promising genotypes which can be exploited in breeding programs.

MATERIAL AND METHODS

The experiments were carried out at Embrapa Hortaliças experimental field, Brasília-DF, (15°56'14'S, 48°08'31'W, 1000 m altitude), during 2017 and 2018. According to Köppen (Kottek *et al*., 2006), the local climate is Aw type, with dry winter. The temperature during the crop cycle ranged from 27.4ºC to 15.8ºC (maximum and minimum, respectively) in 2017, and the temperature ranged from 27.4ºC to 15.7ºC, in 2018. Relative humidity in these two years was 55.6% and average rainfall was 1.7 mm/day (Inmet, 2018).

We evaluated 48 lentil genotypes from International Center for Agricultural Research in the Dry Areas (ICARDA). Cultivar Silvina was used as control (Embrapa Hortaliças, 2014) (Table 1). The soil was classified as Typic Hapludox, the chemical properties in 0-20 cm layer, in 2017, immediately before the beginning of the experiment were: pH (water)= 5.2; pH ($CaCl_2$)= 5.2; organic matter = 3.0%; $P_{(Mehlich)}$= 2.9 mg dm^{-3}; $K_{(Mehlich)}$= 191.59 mg dm^{-3}; $Ca_{(KCl)}$= 0.5 $cmol_c$ dm^{-3}; $Mg_{(KCl)}$= 0.5 $cmol_c$ dm^{-3}; $Al_{(Mehlich)}$= 0.9 $cmol_c$ dm^3; $H+Al_{(SMP)}$= 4.3 $cmol_c$ dm^{-3}; cation exchange capacity at pH 7.0 (CEC)= 5.8 $cmol_c$ dm^{-3}; base saturation (V)= 27%; aluminum saturation (m)= 37%; $B_{(hot\ water)}$= 0.03 mg dm^{-3}; $Cu_{(Mehlich)}$= 1.60 mg dm^{-3}; $Fe_{(Mehlich)}$= 84 mg dm^{-3}; $Mn_{(Mehlich)}$= 22.3 mg dm^{-3}; $Zn_{(Mehlich)}$= 1.90 mg dm^{-3}; $S_{[Ca(H2PO4)2]}$= 2.6 mg dm^{-3}.

The experimental design was randomized blocks with 49 treatments (48 inbred lines and cultivar Silvina), with two replicates in 2017 and three replicates in 2018. The plots consisted of one 4-meter-long row, considering two planting rows, spaced 0.50 m between each other, with 10 plants each, totalizing a useful area of 2.0 m^2 per plot. Sowings were carried out in the same area on May 10th and May 24th, 2017 and 2018, respectively, 30 days after application of 2000 kg ha^{-1} of dolomitic limestone (PRNT 80%), in each of the years, based on the level of base saturation showed by the chemical analysis of the first experimental year. In both experiments, sowing fertilization was carried out using 16 kg ha^{-1} N, 120 kg ha^{-1} P_2O_5 and 64 kg ha^{-1} K_2O in the furrows. Seeds were not inoculated with *Rhizobium* sp. Top-dressing fertilization was performed at 30 days after emergence (DAE) with application of 100 kg ha^{-1} N (urea) (Vieira, 2003).

We used sprinkler irrigation system, with a daily gross water depth (from 5 to 6 mm) according to Giordano *et al*. (1988) recommendation, applied at more frequent intervals during the emergence period until the plants were fully developed. The irrigation was temporarily suspended in two cycle stages: before the beginning of flowering and at the end of the grain filling. This practice is carried out in order to stimulate grain production and maturation, respectively (Vieira & Lima, 2016). A sensor-based device (tensiometer 40 Kpa, brand Irrigas®, model HID02) determined the irrigation shifts. The gadget was installed at two depths (15 and 30 cm) (Marouelli & Calbo, 2009).

Weeds were controlled by hand hoeing throughout the crop cycle. Insecticides and fungicides were not applied, despite some insect-pest had been found in the experiment, such as caterpillars, thrips, aphids, mining larvae and bedbugs, without species identification, and diseases (soil fungus and powdery mildew).

Morpho-agronomic characterization

Genotype characterization was carried out based on fifteen descriptors established by International Union for the Protection of new Varieties of Plants (UPOV, 2015), nine being qualitative traits (growth habit, anthocyanin pigmentation in stem, branching

intensity, leaf color intensity, leaflet shape, flower color, violet streaks on the flower, seed coating color and cotyledon color) and six quantitative traits (number of days until flowering starts, plant height, pod length, seed width and weight of 1000 seeds). Additionally, information was collected on the following quantitative traits: height of the first pod insertion (evaluated at the beginning of the reproductive phase, using a graduated ruler, between the ground level and the first pod of the lower third of the plant), number of pods per plant (counting the number of pods per plant), number of seeds per plant (counting the total number of seeds per plant), seed yield per plant (seed weight, in grams, per plant), productivity (total weight of seeds per plot, in grams) and cycle duration (counting the number of days from sowing to harvest).

Grouping analysis

In order to get information using morpho-agronomic variables, the authors performed multivariate analysis using cluster method (Cruz *et al.*, 2012). Qualitative and quantitative variables have been transformed into binary data. Using these data, the dissimilarity values were calculated using Jaccard's coefficient and projected in a dendrogram created using Unweighted Pair-Group Method Arithmetic Average (UPGMA). Besides, Tocher's optimized method was used to verify coherence of the groups formed in the dendrogram.

Statistical analysis

For qualitative descriptors, the percentual frequencies of each category were calculated and, for quantitative traits, the experimental data were submitted to individual and joint variance analysis, using F test. The authors needed to transform number of pods per plant, number of seeds per plant, seed yield and weight of 1000 seeds to $\sqrt{x+0.5}$ and productivity to log (x + 0.5) assumptions of the analysis of variance. The joint analysis was carried out under conditions of homogeneity of residual variances (Pimentel-Gomes, 2009), using SAS 9.2 software (SAS, 2009). When inbred line x year interaction was significant, the authors decided to unfold this interaction and the average test of double-entry table average test was performed with adjusted averages using the Scott-Knott clustering ($p \leq 0.05$), with the aid of Genes software (Cruz, 2013).

RESULTS AND DISCUSSION

Qualitative traits

Percentage frequency distribution of qualitative traits showed variations among the studied genotypes (48 inbred lines + cultivar Silvina). Semi-erect growth habit was verified in 46.9% of genotypes, followed by erect growth habit (40.9%) and by prostrate growth habit (12.2%). Only 8.2% of genotypes showed anthocyanin pigmentation in the stem, which was completely absent (green stem) for the rest 91.8%.

For branching intensity, 91.8% of genotypes showed the strong variant, whereas the weak variant was verified in 8.2% genotypes. The leaf color intensity for medium-green hue was predominant (91.8%), whereas strong green color occurred in 8.2% of the genotypes. The authors observed that the difference between the leaf color intensity variant might have been influenced by luminosity at the moment of evaluation, as well as by soil nitrogen level (Ferreira *et al*., 2011). The oval leaflet shape (59.2%) predominated in relation to the elliptical one (40.8%).

White flowers were observed in 97.9% of the genotypes. Only FLIP2009-15L showed light pink flowers. This trait is important for verifying the varietal purity (Roy *et al*., 2012), since the parameter "flower color" can vary depending on the genotype, flower age and environmental conditions (Sharma, 2009). All the genotypes showed violet streaks on the flowers.

Red-coated seeds showing orange cotyledon were found in 43 genotypes (87.8%). Green coating was observed in 12.2% and green cotyledon in 10.2% of the genotypes. Only cultivar Silvina showed yellow cotyledon.

Quantitative traits

Quantitative traits evaluated in this study were influenced by genotypes and/or year of evaluation, showing significant differences ($p \leq 0.05$), except for plant height (Table 2). Significant interaction ($p \leq 0.05$) year x genotype was observed only for number of days until flowering beginning. Thus, studies on the unfolding of these factors were carried out (Table 3).

The number of days until the flowering beginning ranged from 50 to 107.5 in the first year (2017) and from 59 to 92 in the second year (2018) (Table 3). Vieira (2003), working with lentil genotypes from ICARDA, in Coimbra-MG, verified values similar to the ones found in this study for flowering beginning (60 and 102 days after sowing). Cultivar Silvina stood out among the genotypes in two years of evaluation, maintaining its early-flowering pattern and presenting 50% of the plants with, at least, one flower open at 50 days and 59 days in the first and second years, respectively. Genotype FLIP2010-20L did not differ from cultivar Silvina in the second year of the experiment, showing flowering beginning at 65 days. Genotypes 81S15, FLIP2007-28L, FLIP2007-74L, FLIP2007-77L, FLIP2009-2L, FLIP2009-4L, FLIP2009-7L, FLIP2009-15L, FLIP2009-18L, FLIP2009-27L, FLIP2010-19L and FLIP2010-21L flourished later in these two years. Comparing the two years of experiment, we observed a decrease in number of days for flowering beginning in 23 genotypes, with an average reduction of 8.5 days and 24.2 days in genotypes FLIP2010-32L and 6031, respectively (Table 3). Delayed sowing could have been the responsible for this result in the second year (14 days), since the average temperature of sowing up to flowering beginning were similar in both years (max. 26.4ºC and min. 14.8ºC in 2017; max. 26.6ºC and min. 14.3ºC in 2018).

No significant effect concerning genotypes and year for plant height was noticed (Table 2). Despite this, all genotypes showed a numerical value for plant height above the value obtained by cultivar Silvina (Table 3). Lentil plants can vary from 20 to 75 cm high, depending on the genotype and growing conditions (Saxena, 2009).

In relation to insertion height of the

Table 1. Identification, pedigree and origin of 48 lentil inbred lines (*Lens culinaris*) from International Center for Agricultural Research in the Dry Areas (ICARDA) and commercial cultivar Silvina. Brasília, Embrapa Hortaliças, 2020.

Nº	Genotype	Pedigree	Origin
01	81S15	UJL 197 x ILL 4400	JORDAN
02	FLIP90-25L	ILL 5588 x ILL 99	ICARDA
03	FLIP2007-11L	ILL 2126 x ILL 1005	ICARDA
04	FLIP2007-16L	ILL 2126 x ILL 4659	ICARDA
05	FLIP2007-28L	ILL 590 x ILL 5769	ICARDA
06	FLIP2007-42L	ILL 7201 x ILL 5728	ICARDA
07	FLIP2007-74L	ILL 590 x ILL 6434	ICARDA
08	FLIP2007-75L	ILL 590 x ILL 1005	ICARDA
09	FLIP2007-77L	ILL 1939 x ILL 8090	ICARDA
10	FLIP2008-2L	ILL 857 x AKM 362	ICARDA
11	FLIP2009-1L	ILL 7620 x ILL 7686	ICARDA
12	FLIP2009-2L	ILL 7620 x ILL 7686	ICARDA
13	FLIP2009-4L	ILL 6991 x ILL 7686	ICARDA
14	FLIP2009-5L	ILL 6991 x ILL 7686	ICARDA
15	FLIP2009-7L	ILL 5883 x ILL 7706	ICARDA
16	FLIP2009-9L	ILL 7502 x ILL 6994	ICARDA
17	FLIP2009-10L	ILL 7502 x ILL 6994	ICARDA
18	FLIP2009-11L	ILL 8077 x ILL 6994	ICARDA
19	FLIP2009-12L	ILL 8077 x ILL 6994	ICARDA
20	FLIP2009-13L	ILL 8077 x ILL 6994	ICARDA
21	FLIP2009-14L	ILL 8077 x ILL 6994	ICARDA
22	FLIP2009-15L	ILL 6778 x ILL 6994	ICARDA
23	FLIP2009-16L	ILL 5588 x ILL 7979	ICARDA
24	FLIP2009-17L	ILL 5588 x ILL 8188	ICARDA
25	FLIP2009-18L	ILL 5883 x ILL 6994	ICARDA
26	FLIP2009-19L	ILL 5883 x ILL 6994	ICARDA
27	FLIP2009-25L	ILL 5883 x ILL 6994	ICARDA
28	FLIP2009-26L	ILL 5883 x ILL 6994	ICARDA
29	FLIP2009-27L	ILL 5883 x ILL 6994	ICARDA
30	FLIP2010-2L	ILL 2126 x ILL 4637	ICARDA
31	FLIP2010-8L	ILL 2126 x ILL 6199	ICARDA
32	FLIP2010-12L	ILL 6199 x ILL 2126	ICARDA
33	FLIP2010-19L	ILL 0590 x ILL 5769	ICARDA
34	FLIP2010-20L	ILL 0590 x ILL 5769	ICARDA
35	FLIP2010-21L	ILL 7012 x ILL 2125	ICARDA
36	FLIP2010-22L	ILL 7012 x ILL 2125	ICARDA
37	FLIP2010-23L	ILL 7012 x ILL 2125	ICARDA
38	FLIP2010-24L	ILL 2126 x ILL 6199	ICARDA
39	FLIP2010-27L	ILL 6024 x ILL 0098	ICARDA
40	FLIP2010-28L	ILL 8090 x ILL 6783	ICARDA
41	FLIP2010-29L	ILL 8090 x ILL 6783	ICARDA
42	FLIP2010-30L	ILL 8090 x ILL 7685	ICARDA
43	FLIP2010-31L	ILL 8090 x ILL 7685	ICARDA
44	FLIP2010-32L	ILL 8090 x ILL 7685	ICARDA
45	FLIP2010-99L	ILL 7620 x 91517	ICARDA
46	FLIP2010-100L	ILL 2501 x ILL 5737	ICARDA
47	FLIP2010-106L	ILL 7723 x ILX 87062	ICARDA
48	SILVINA	-	EMBRAPA
49	6031	ILL 101 x ILL 162	ICARDA

first pod, no significant difference was observed among the genotypes, the lowest numerical value being observed for the cultivar Silvina, 16.82 cm. Lentil plants with pods from 10 to 15 cm high in relation to soil can favor a better phytosanitary state of the seeds and less loss in mechanized harvest (Diekmann & Al-Saleh, 2009). Thus, all the genotypes showed appropriate standard for this trait.

Genotypes FLIP2010-27L, FLIP2010-100L, FLIP2009-19L, FLIP2009-11L, FLIP2010-106L and FLIP2009-1L made up the group with the highest average for the number of pods per plant (Table 3). The longest pods were obtained by cultivar Silvina (14.42 mm), differing statistically from the genotypes. However, in relation to pod width, the genotypes FLIP2010-2L and FLIP 2010-19L (7.27 mm), FLIP2007-11L (7.68 mm) and FLIP2007-16L (7.40 mm) did not differ statistically from cultivar Silvina (7.96 mm). For seed yield per plant, these four genotypes differed statistically from cultivar Silvina, though.

Genotypes FLIP2007-11L, FLIP2010-2L, FLIP2010-19L and cultivar Silvina showed larger seeds, this being different from the others (Table 3). Cultivar Silvina showed the greatest weight of one thousand seeds (53.47 g), followed by genotypes FLIP 2007-16L (52.11 g), FLIP 2010-2L (49.70 g), FLIP 2007-11L (48.63 g), FLIP 2010-8L (48.55 g) and FLIP 2010-12L (43.45 g). The genotype FLIP 2009-15L showed the lowest weight (20.59 g) (Table 3).

In relation to productivity, Silvina is considered one of the most productive cultivar, showing much superior average productivity (2.259 kg ha^{-1}) in relation to worldwide average (1.042 kg ha^{-1}) (Faostat, 2020). Cultivar Silvina and the genotype 6031 showed to be earlier in terms of cycle length; twelve genotypes showed intermediate cycle and 35 genotypes late cycle (Table 3).

Genetic divergence

Considering 21 evaluated morpho-genetic traits, a dendrogram was created (Figure 1) showing the formation of five groups, at 40% similarity level, obtaining an acceptable cophenetic

Table 2. Summary of the joint analysis of variance for quantitative morpho-agronomic traits of 48 lentil inbred lines (*Lens culinaris*) and the commercial cultivar Silvina in two years, 2017 and 2018. Brasília, Embrapa Hortaliças, 2020.

		Medium square											
FV	**GL**	**NDIF**	**APLA**	**IVAG**	**CVAG**	**LVAG**	**NVAG**	**NSEM**	**RSEM**	**LSEM**	**P1000**	**PROD**	**CI**
Year (A)	1	2777.77**	14.86^{ns}	2488.72**	4.35^{ns}	4.61^{ns}	382.97**	201.92**	2.92**	9.83**	67.36**	0.10^{ns}	0.00^{ns}
Genotype (G)	48	11147.82**	3244.22^{ns}	1549.05^{ns}	343.91**	72.92**	698.99^{ns}	714.48**	19.35**	60.66**	144.50^{ns}	7.04**	6891.89**
A X G	47	4297.19**	2167.32^{ns}	1214.88^{ns}	60.53^{ns}	19.42^{ns}	253.66^{ns}	142.83^{ns}	3.42^{ns}	18.84^{ns}	79.71^{ns}	2.43^{ns}	1422.66^{ns}
Averages		85.25	49.84	25.07	10.38	6.17	73.06	46.44	1.38	4.29	5.43	307.0	143.94
CV (%)		7.03	12.38	17.58	10.58	8.91	31.14	32.67	23.08	17.30	13.05	22.40	4.95

^{ns} non-significant (p< 5%); ** significant (p<5%), by the F test; FV= variation source; GL= degrees of freedom; NDIF= number of days until flowering; APLA= plant height; IVAG= height of the first pod insertion; CVAG= pod length; LVAG= pod width; NVAG= number of pods per plant; NSEM= number of seeds per plant; RSEM= seed yield; LSEM= seed width; P1000= weight of 1000 seeds; PROD= productivity and CI= crop cycle duration.

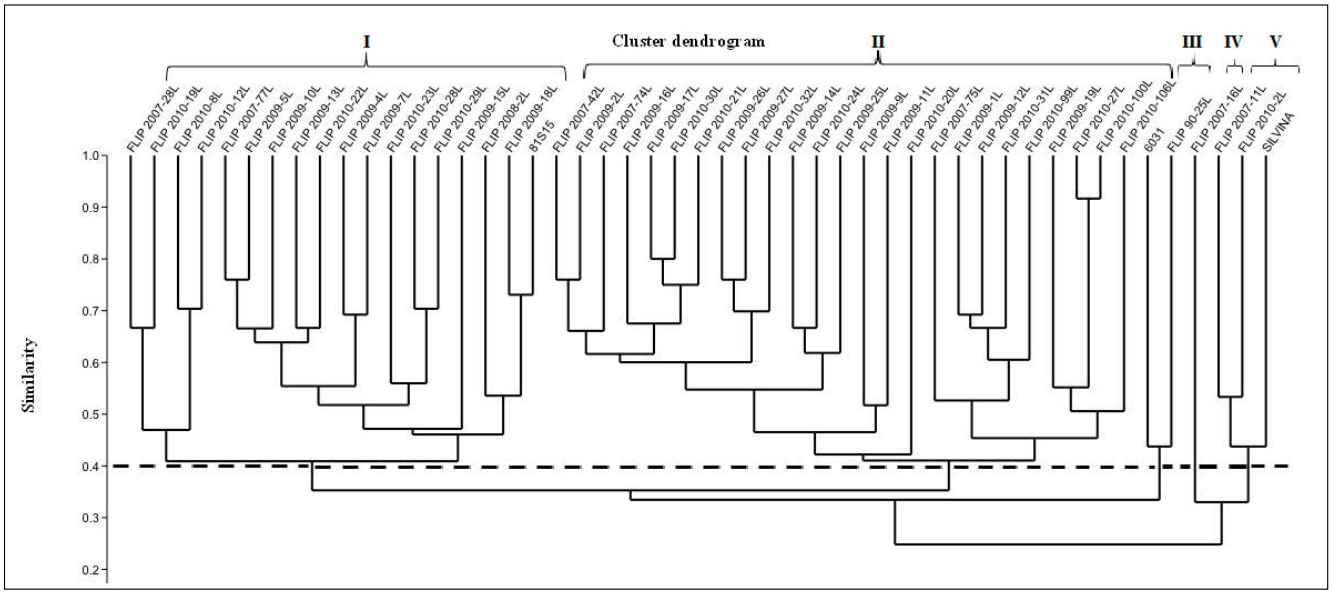

Figure 1. Dendrogram based on the UPGMA grouping of 48 lentil inbred lines (*Lens culinaris*) and commercial cultivar Silvina, based on 21 morpho-agronomic traits. Brasília, Embrapa Hortaliças, 2020.

coefficient (0.76). Groups I to III were composed of inbred lines classified as microsperm, showing red coating color of the seed and orangish cotyledon, and groups IV and V by macrosperm genotypes, with green-coated seeds and green and yellow cotyledons.

Group I consisted of 18 genotypes, these being most genotypes which showed erect growth habit, average branching intensity, the highest plants, height of the first pod insertion and 1000 seed weight among microsperms. Group II consisted of 25 genotypes, the majority with a semi-erect growth habit, strong branching intensity, medium color intensity of the leaf, the largest variations in leaflet shape considering oval and elliptical, the lowest average number of days until flowering beginning among microsperms, the highest averages for pod length and width, number of seeds per plant, seed yield and width. Group II included the most productive genotype among microsperms (FLIP 2010-99L).

Group III consisted of two genotypes with the smallest seed width among microsperms and the earliest cycle. The average productivity of this group was 410.84 kg ha^{-1}, the highest productivity compared with groups I and II.

The genotype in group IV showed semi-erect growth habit, branching intensity and intensity of the leaf color characterized as strong, seeds coated with green cotyledons.

Group V, composed of three genotypes, showed similarity varying from 35% (FLIP2007-16L in relation to others) to 55% (FLIP2007-11L and FLIP2010-2L), with genotypes showing erect growth habit. Genotypes FLIP2007-11L and cultivar Silvina presented anthocyanin pigmentation in the stems, green-coated seeds, green (FLIP2007-11L and FLIP2010-2L) and yellow (Silvina) cotyledons, the longest and widest pods, the greatest number of seeds per plant, the highest seed yield per plant and the highest productivity. This group also presented the earliest genotype among those of macrosperm type, it means, cultivar Silvina.

Partial coincidence was observed among groups formed by Tocher's test and by the dendrogram. Six groups were formed by the Tocher's method (Table 4), and five groups were obtained by cutting the dendrogram (Figure 1).

Table 3. Average values of the number of days until flowering (NDIF), plant height (APLA), height of first pod insertion (IVAG), pod length (CVAG), pod width (LVAG), number of pods per plant (NVAG), number of seeds per plant (NSEM), seed yield per plant (RSEM), seed width (LSEM), weight of 1000 seeds (P1000), productivity (PROD) crop cycle duration (CI) of 48 lentil inbred lines and cultivar Silvina in two years, 2017 and 2018. Brasília, Embrapa Hortaliças, 2020.

N	Genotype	NDIF (Years)		APLA (cm)	IVAG (cm)	CVAG (mm)	LVAG (mm)	NVAG
		2017	2018					
1	81S15	93.0aA	92.0 aA	51.80	26.45	9.78e	6.27c	34.18
2	FLIP90-25L	84.0bA	79.0bA	49.40	26.59	9.08f	5.65d	103.79
3	FLIP2007-11L	89.5aA	79.0bB	48.48	25.40	13.38b	7.68a	78.69
4	FLIP2007-16L	73.5bA	77.0bA	50.78	26.95	13.04b	7.40a	34.61
5	FLIP2007-28L	93.0aA	92.0aA	48.21	26.09	11.98c	7.15b	46.06
6	FLIP2007-42L	82.5bB	87.0aA	52.52	26.66	10.27e	6.17c	65.29
7	FLIP2007-74L	89.5aA	92.0aA	56.48	26.13	10.05e	6.29c	57.33
8	FLIP2007-75L	84.0bA	79.0bA	53.59	26.66	10.30e	6.43c	83.92
9	FLIP2007-77L	98.5aA	92.0 aA	52.56	29.60	9.57f	5.70d	39.09
10	FLIP2008-2L	84.0bA	80.0bA	52.70	32.68	10.13e	6.27c	63.80
11	FLIP2009-1L	79.0bA	79.0bA	52.35	20.58	11.07d	6.67b	144.88
12	FLIP2009-2L	95.0aA	92.0aA	46.88	25.08	10.66e	6.30c	69.12
13	FLIP2009-4L	95.0aA	90.5aA	53.51	26.95	8.86f	5.85c	99.73
14	FLIP2009-5L	97.0 aA	79.0bB	56.35	26.60	8.98f	5.68d	28.87
15	FLIP2009-7L	95.0 aA	91.0aA	50.89	28.44	9.13f	5.89c	54.41
16	FLIP2009-9L	98.5aA	85.5bB	50.41	23.84	8.17g	5.25e	105.68
17	FLIP2009-10L	93.0aA	81.0bB	50.39	28.16	8.71f	5.49d	70.55
18	FLIP2009-11L	77.5bA	79.7bA	42.44	22.06	9.40f	5.74d	153.10
19	FLIP2009-12L	78.5bA	80.3bA	50.93	23.35	11.01d	6.09c	110.77
20	FLIP2009-13L	95.0aA	83.3bB	52.18	26.30	9.46f	5.97c	66.74
21	FLIP2009-14L	91.5 aA	80.0bB	48.65	24.20	10.09e	5.86c	90.30
22	FLIP2009-15L	91.5 aA	92.0aA	49.76	24.52	8.90f	5.23e	49.37
23	FLIP2009-16L	98.5 aA	77.0bB	50.01	23.84	9.53f	5.26e	58.05
24	FLIP2009-17L	91.5 aA	77.3bB	53.21	25.18	10.78e	6.39c	62.60
25	FLIP2009-18L	93.5 aA	92.0aA	50.80	27.60	9.85e	6.19c	38.39
26	FLIP2009-19L	91.5 aA	79.0bB	43.83	19.50	9.95e	6.53c	160.50
27	FLIP2009-25L	98.5 aA	79.0bB	46.91	23.66	9.86e	6.07c	104.54
28	FLIP2009-26L	95.0aA	83.5bB	50.45	22.53	9.56f	6.12c	86.54
29	FLIP2009-27L	93.0aA	92.0aA	56.64	25.36	9.36f	6.11c	65.41
30	FLIP2010-2L	95.0aA	81.0bB	49.82	24.36	12.31c	7.27a	55.25
31	FLIP2010-8L	95.0aA	80.5bB	57.11	26.50	11.92c	6.61b	28.51
32	FLIP2010-12L	101.5 aA	78.3bB	47.27	26.78	12.43c	6.92b	36.15
33	FLIP2010-19L	93.0aA	87.0aA	49.82	24.36	12.31c	7.27a	55.25
34	FLIP2010-20L	88.0 aA	65.0cB	57.11	26.50	11.92c	6.61b	28.51
35	FLIP2010-21L	93.0aA	88.7aA	47.27	26.78	12.43c	6.92b	36.15
36	FLIP2010-22L	91.5aA	77.0bB	46.60	24.85	9.11f	5.75d	47.73
37	FLIP2010-23L	100.5aA	83.7bB	53.14	25.87	9.56f	6.02c	45.75
38	FLIP2010-24L	77.5bA	82.3bA	48.03	22.82	10.28e	6.25c	66.10
39	FLIP2010-27L	74.5bA	79.0bA	44.14	22.64	10.77e	6.38c	182.92
40	FLIP2010-28L	101.5 aA	82.0bB	51.79	26.42	7.46g	4.62e	45.42
41	FLIP2010-29L	95.0 aA	84.3bB	51.24	25.56	9.33f	5.69d	82.50
42	FLIP2010-30L	89.5 aA	79.0bB	52.48	22.43	9.82e	6.25c	87.47
43	FLIP2010-31L	93.0 aA	72.3bB	49.52	23.33	10.93d	6.13c	103.65
44	FLIP2010-32L	87.5 aA	79.0bB	50.97	26.08	9.64f	6.03c	93.46
45	FLIP2010-99L	79.5bA	76.0bA	45.03	21.10	10.74e	6.34c	114.38
46	FLIP2010-100L	82.5bA	85.5bA	40.15	20.70	10.52e	5.90c	173.68
47	FLIP2010-106L	71.0bA	81.7bA	49.99	19.94	11.47d	5.81d	148.23
48	SILVINA	50.0cB	59.0cA	37.70	16.82	14.42a	7.96a	81.24
49	6031	107.5aA	83.3bB	43.71	23.55	11.34d	5.63d	64.01

Table 3. continuation

N	Genotype	NSEM	RSEM (g plant^{-1})	LSEM (mm)	P1000 (g 1000^{-1})	PROD (kg ha^{-1})	CI (days)
1	81S15	19.57d	0.47d	4.30c	28.04	143.48b	143a
2	FLIP90-25L	68.06b	1.64c	3.88d	26.12	604.40a	137b
3	FLIP2007-11L	46.68c	2.06b	5.79a	48.63	433.73a	140b
4	FLIP2007-16L	26.38d	1.13c	5.13b	52.11	294.48a	144a
5	FLIP2007-28L	23.60d	0.97d	4.50c	36.30	92.53b	145a
6	FLIP2007-42L	43.29c	1.16c	4.50c	32.14	222.55b	144a
7	FLIP2007-74L	37.57c	1.38c	4.08c	32.21	187.30b	148a
8	FLIP2007-75L	71.69b	2.71b	4.75b	32.82	335.64a	144a
9	FLIP2007-77L	23.79d	0.50d	3.68d	25.09	74.85b	148a
10	FLIP2008-2L	29.72d	0.95d	4.44c	36.88	186.03b	140b
11	FLIP2009-1L	89.55b	2.63b	4.51c	28.99	399.68a	147a
12	FLIP2009-2L	56.88c	1.60c	4.18c	29.03	486.78a	146a
13	FLIP2009-4L	38.68c	0.92d	4.03c	24.50	118.93b	149a
14	FLIP2009-5L	7.59d	0.07d	3.57d	23.31	139.80b	150a
15	FLIP2009-7L	36.71c	0.98d	4.21c	26.20	229.38b	145a
16	FLIP2009-9L	45.71c	1.20c	3.46d	21.21	42.65b	153a
17	FLIP2009-10L	61.16c	0.88d	3.58d	22.75	80.08b	142a
18	FLIP2009-11L	63.26b	1.62c	4.12c	23.10	290.68b	148a
19	FLIP2009-12L	79.62b	2.61b	4.51c	29.79	421.07a	138b
20	FLIP2009-13L	26.70d	0.64d	3.17d	25.84	217.98b	147a
21	FLIP2009-14L	55.01c	1.37c	4.43c	28.89	363.83a	143a
22	FLIP2009-15L	30.72d	0.73d	3.32d	20.59	207.85b	148a
23	FLIP2009-16L	44.60c	1.11c	3.99c	27.13	100.50b	144a
24	FLIP2009-17L	41.59c	1.15c	4.23c	31.20	175.88b	148a
25	FLIP2009-18L	23.40d	0.67d	4.17c	29.47	104.13b	140b
26	FLIP2009-19L	129.83a	3.42a	4.20c	24.84	469.34a	148a
27	FLIP2009-25L	59.06c	1.49c	4.42c	28.57	102.03b	138b
28	FLIP2009-26L	48.59c	1.27c	4.42c	28.44	272.35b	145a
29	FLIP2009-27L	51.69c	1.61c	4.30c	29.25	378.55a	144a
30	FLIP2010-2L	33.10c	1.45c	5.47a	49.70	239.93b	149a
31	FLIP2010-8L	15.09d	0.55d	5.19b	48.55	225.65b	148a
32	FLIP2010-12L	21.96d	0.61d	4.72b	43.45	141.59b	144a
33	FLIP2010-19L	33.10c	1.45c	5.47a	35.93	188.41b	149a
34	FLIP2010-20L	15.09d	0.55d	5.19b	38.06	714.00a	148a
35	FLIP2010-21L	21.96d	0.61d	4.72b	30.50	166.19b	144a
36	FLIP2010-22L	25.91d	0.62d	3.83d	24.40	68.63b	148a
37	FLIP2010-23L	38.54c	0.61d	5.07b	29.05	150.95b	146a
38	FLIP2010-24L	40.34c	1.18c	4.26c	28.78	242.75b	141b
39	FLIP2010-27L	152.29a	4.49a	4.54c	28.30	426.82a	140b
40	FLIP2010-28L	14.12d	0.31d	3.14d	32.09	56.54b	140b
41	FLIP2010-29L	40.41c	0.91d	3.90d	27.00	122.49b	141b
42	FLIP2010-30L	53.21c	1.82c	4.31c	27.98	121.37b	146a
43	FLIP2010-31L	77.68b	2.11b	4.22c	29.15	323.05a	146a
44	FLIP2010-32L	50.75c	1.68c	3.95c	24.03	230.07b	144a
45	FLIP2010-99L	85.34b	2.62b	4.52c	31.78	976.91a	138b
46	FLIP2010-100L	149.37a	4.34a	4.10c	28.49	325.23a	138b
47	FLIP2010-106L	134.68a	4.15a	4.24c	30.37	682.67a	143a
48	SILVINA	71.42b	3.74a	5.73a	53.47	2259.03a	127c
49	6031	47.50c	1.39c	3.86d	26.68	217.29b	133c

*****averages followed by the same lowercase letter in the column and uppercase letter in the line belong to the same group by the Scott and Knott test (p< 5%).

Table 4. Grouping through Tocher's method based on the calculated distance by Jaccard's method among 49 lentil genotypes, 48 experimental inbred lines and the commercial cultivar Sílvina. Brasília, Embrapa Hortaliças, 2020.

Group (number)	Genotypes
1	FLIP 2007-74L; FLIP 2009-17L; FLIP 2007-42L; FLIP 2010-32L; FLIP 2009-26L; FLIP 2010-30L; FLIP 2010-24L; FLIP 2010-22L; FLIP 2009-25L; FLIP 2010-29L; FLIP 2007-77L; FLIP 2009-18L; FLIP 2009-7L; FLIP 90-25L; FLIP 2009-14L; FLIP 2009-15L; FLIP 2009-13L; FLIP 2009-16L; FLIP 2009-2L; FLIP 2009-27L; 81S15; FLIP 2010-23L; FLIP 2010-20L; FLIP 2009-4L; FLIP 2009-9L; FLIP 2009-5L; FLIP 2010-28L; FLIP 2010-99L; FLIP 2009-10L; FLIP 2009-11L; FLIP 2009-1L; FLIP 2007-75L; FLIP 2010-31L; FLIP 2009-12L; FLIP 2008-2L
2	FLIP 2010-21L
3	FLIP 2009-19L
4	FLIP 2010-27L; FLIP 2010-100L; FLIP 2010-106L; 6031
5	FLIP 2010-2L; FLIP 2010-8L; FLIP 2010-19L; FLIP 2007-11L; FLIP 2007-16L; FLIP 2010-12L; FLIP 2007-28L
6	Silvina

Of the 35 genotypes grouped in the first group by the Tocher's test, 34 were covered by groups I and II of the dendrogram. Groups II, III and IV of the Tocher's test were fully contemplated by group II from the dendrogram, except genotype 6031, included in group III from the dendrogram. Genotypes, macrosperm type (FLIP 2010-8L, FLIP 2007-16L, FLIP 2007-11L, FLIP 2010-2L and Silvina), were distributed among groups I, IV and V of the dendrogram; however, they were all gathered in group V by Tocher's test, except Silvina, who formed an isolated group in this last test.

Grouping data themselves do not allow to define crosses, as the genetically distinct inbred lines do not necessarily have the best combining ability (Vaz *et al*., 2017). We should also take into consideration the best averages for traits of interest among the contrasting inbred lines, allowing more frequent combination among superior genotypes (Cruz *et al*., 2012). Thus, taking into consideration traits such as growing habit, seed coating color, cotyledon color, plant height, number of days until flowering beginning, weight of 1000 seeds and productivity, inbred lines FLIP2010-8L and FLIP2010-12L (group I), FLIP2010-99L, FLIP2010-20L and FLIP2010-106L (group II), FLIP90-25L and 6031 (group III), FLIP2007-16L (group IV) and commercial cultivar Silvina (group V) showed to be more promising to be used in breeding programs of the species.

Genotypes FLIP2010-99L, FLIP2010-20L, FLIP2010-106L and FLIP90-25L showed the best averages for traits of commercial interest within microsperm group. In macrosperm group, cultivar Silvina showed outstandingly high productivity values. As a matter of fact, in this study, no genotype, macrosperm type, was identified as superior to the already existing commercial cultivar. Using the association of grouping techniques with characterization data, we could identify divergent and, at the same time, superior genotypes regarding agronomic traits: FLIP2010-8L and FLIP2010-12L (group I), FLIP2010-99L, FLIP2010-20L and FLIP2010-106L (group II), FLIP90-25L and 6031 (group III), FLIP2007-16L (group IV) and the commercial cultivar Silvina (group V). These genotypes showed potential for being used in breeding programs of the species.

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