Quality variation of fruits of species of the genus Lycium in Ukraine: A comparative morphological analysis

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Introduction

The genus Lycium L. (Solanaceae Juss.) includes about 92(97) species, widespread in temperate and subtropical zones. Its shrubs or small trees are mostly found in arid or semi-arid, semisubtropical environments (Levin et al., 2011; Barboza et al., 2016). 35 species from all genera are used as food or medicine (Yao et al., 2018a).

But goji berries are the most used in the quality of ‘superfruit’. Under this name, the fruits of two species from east Asia: L. barbarum Mill. and L. chinense L. (Solanaceae Juss.) includes about 92(97) species and varieties. These two species are the most common species in both hemispheres (GBIF.org, http://doi.org/10.15468/ dl23cety6, http://doi.org/10.15468/dllaf62g). In Europe, including Ukraine, both species have naturalized and are neo-phytes, a component of the synantropic flora (Mosyakin et al., 1999; Pyšek et al., 2002).

The purpose of this study was to determine the variability of some morphological characteristics of fruits Lycium spp. The obtained results will help to select promising genotypes for future breeding work and to evaluate the prospects of promising use of selected samples.

Materials and methods

The plants were grown in M. M. Gryshko National Botanical Garden of NAS of Ukraine (Kyiv) from seeds or cuttings obtained from China, France, Slovak Republic and other Botanical Gardens of Ukraine. There 21 genotypes were investigated in an experimental study 2016–2019, including three species (Lycium barbarum, L. chinense, L. truncatum) and 10 cultivars and 11 varieties (LB01–LB03, LC01–LC05, LT01). Samples were marked as LB (L. barbarum), LC (L. chinense), LT (L. truncatum).

30 fruits from each genotype were used immediately after harvest for phenotypic measurements such as fruit weight, (FW), in g, fruit length (FL), in mm, fruit diameter (FD), in mm. Fruit mass was measured by using a digital balance with a sensitivity of 0.01 g (PS6000/C/1). Linear dimensions of fruits as length and diameter were measured by using a

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digital calliper gauge with a sensitivity of 0.01 mm, then the shape index was calculated by using length/width ratio. Basic statistical analyses – the minimal and maximal values of the traits, arithmetic means, and coefficient of variation (V, %) were performed using PAST 2.17 (Norway, 2001). Results of the morphometric analysis were determined by mean ± standard deviation (SD) and statistical significance was estimated. Hierarchical cluster analyses of similarity between phenotypes were computed by the Bray-Curtis similarity index and were performed using PAST 2.17.

**Results**

The differences in weight, shape, size, colour of fruits from the collection of the M. M. Gryshko National Botanical Garden are shown in Figure 1. The minimum and maximum values for the weight, length, diameter, shape index of fruit, and number of seeds in the twenty-one *Lycium* spp. are shown in Table 1.

![Fig. 1. Variability of fruits of *Lycium* spp.](image)

**Table 1**

| Species, cultivars, varieties | Fruit weight, g | Fruit length, mm | Fruit diameter, mm | Shape index | Number of seeds in fruit |
|------------------------------|-----------------|------------------|--------------------|-------------|-------------------------|
|                              | min             | max              | min                | max         | min         | max         | min     | max     | min     | max     |
| *Lycium barbarum*            |                 |                  |                    |             |             |             |         |         |         |         |
| LB01                         | 0.25            | 1.24             | 14.00              | 23.00       | 5.00        | 10.00       | 1.56    | 3.20    | 5       | 29      |
| LB02                         | 0.54            | 1.70             | 15.71              | 27.84       | 7.77        | 11.40       | 1.85    | 2.74    | 5       | 35      |
| LB03                         | 0.41            | 1.30             | 13.74              | 22.65       | 7.09        | 10.63       | 1.69    | 2.61    | 5       | 29      |
| LB Wild                      | 0.10            | 1.07             | 6.11               | 22.25       | 3.51        | 11.60       | 1.00    | 2.58    | 1       | 16      |
| *Lycium chinense*            |                 |                  |                    |             |             |             |         |         |         |         |
| LC01                         | 0.68            | 1.13             | 15.70              | 19.07       | 8.22        | 10.49       | 1.57    | 2.21    | 12      | 32      |
| LC02                         | 0.31            | 0.67             | 11.17              | 14.43       | 6.23        | 9.11        | 1.37    | 1.93    | 10      | 26      |
| LC03                         | 0.56            | 1.25             | 15.00              | 20.00       | 7.00        | 10.00       | 1.78    | 2.57    | 15      | 31      |
| LC04                         | 0.68            | 1.52             | 9.78               | 21.09       | 8.07        | 11.80       | 1.03    | 2.27    | 10      | 34      |
| LC05                         | 0.54            | 1.47             | 15.00              | 19.00       | 8.00        | 11.00       | 1.60    | 2.25    | 10      | 30      |
| LC Amber Sweet               | 0.51            | 1.71             | 13.04              | 21.60       | 7.09        | 11.30       | 1.38    | 2.24    | 6       | 17      |
| LC Big Lifeberry             | 0.49            | 1.13             | 16.00              | 20.00       | 8.00        | 10.50       | 1.70    | 2.38    | 13      | 35      |
| LC Delikat                   | 0.61            | 1.24             | 9.00               | 12.00       | 11.00       | 16.00       | 0.67    | 0.92    | 13      | 30      |
| LC Q1                        | 0.43            | 1.07             | 15.00              | 22.00       | 7.00        | 10.00       | 1.67    | 2.79    | 5       | 23      |
| LC Sweet Lifeberry           | 0.54            | 0.85             | 13.99              | 19.34       | 7.06        | 9.82        | 1.69    | 2.28    | 17      | 28      |
| LC Tybet                     | 0.65            | 1.52             | 13.00              | 19.00       | 8.00        | 11.50       | 1.27    | 1.89    | 8       | 38      |
| *Lycium truncatum*           |                 |                  |                    |             |             |             |         |         |         |         |
| LT01                         | 0.27            | 0.93             | 10.88              | 17.30       | 6.13        | 11.06       | 1.27    | 1.85    | 13      | 33      |
| LT Super Sweet               | 0.48            | 1.68             | 15.69              | 28.27       | 6.40        | 11.43       | 2.08    | 3.18    | 9       | 37      |
| LT Korean Big                | 0.23            | 0.66             | 15.66              | 20.48       | 6.04        | 9.95        | 1.34    | 2.50    | 8       | 42      |
| LT N1 Lifeberry              | 0.43            | 0.94             | 14.18              | 22.24       | 6.48        | 9.68        | 1.69    | 2.69    | 11      | 49      |
| LT New Big                   | 0.55            | 1.29             | 18.47              | 25.89       | 6.93        | 9.72        | 2.17    | 3.09    | 18      | 36      |
| LT Princess Tao              | 0.31            | 0.61             | 12.09              | 16.92       | 5.66        | 2.37        | 1.48    | 2.51    | 5       | 31      |

*Note: min – minimal value; max – maximal value.*

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Variation limits for fruit length varied between 6.11 mm for cv. Wild (L. barbarum) to 28.27 mm for cv. Super Sweet (L. truncatum, Table 1). The value of diameter varied within the interval from 3.51 mm (L. barbarum cv. Wild) to 11.80 mm (L. chinense cv. LC 04). Fruit weight, economically the most important characteristic, ranged of 0.10 g (L. barbarum cv. Wild) to 1.71 g (L. chinense cv. Amber Sweet). In this experiment, the average weight of a single fruit exceeded 1 g in the case of: LB 02, LC 04, LC 05, LC Amber Sweet, LC Tybet and LT Super Sweet. The average weight of the fruits was determined in the range of 0.44 (L. truncatum cv. Princess Tao) to 1.08 g (L. chinense cv. Tybet), fruits length from 7.16 (L. truncatum cv. Princess Tao) to 13.48 mm (L. chinense cv. Delikat), Fig. 2, 3). The shape index (Fig. 4) of fruits ranged from 0.78 (L. chinense cv. Delikat) to 2.56 (L. truncatum cv. New Big).

Number of seeds in fruit was identified in the range from 1 (LB Wild) to 49 (LT N1 Lifeberry). Lycium barbarum fruit contains 1–35 seeds, L. chinense – 5–38, L. truncatum – 5–49 seeds. These results indicate the great variability of this trait. The analysis of coefficient of variation showed the significant variability of morphological signs between Lycium spp. cultivars and varieties. The variation coefficients (%) ranged between 11.41 (L. chinense cv. Q1) and 37.12 (L. chinense cv. Delikat) for fruit weight, between 4.31 mm (L. chinense cv. Q1) and 20.40 (L. chinense cv. Delikat) for fruit length, between 5.05 (L. chinense var. LC 05) and 14.09 (L. chinense cv. Delikat) for fruit diameter, between 4.51 (L. truncatum cv. N1 Lifeberry) and 14.44 (L. chinense cv. Delikat) for the shape index, and between 9.73 (L. truncatum cv. N1 Lifeberry) and 60.78 (L. chinense cv. Delikat) for number of seeds in fruits. Data showed that the most variable important selection signs are the fruit weight and number of seeds in fruits. These results indicate the promise of breeding in this way of investigation.

The above data shown in Figures 2–5 are confirmed by cluster analysis. In clustering, all studied parameters for 21 cultivars and varieties of the Lycium spp. were used, and the resulting clusters are shown in Figure 6. On the basis of data presented in Figure 6 it could be said that cluster analysis separates Lycium spp. selections into three main Clusters.
Fig. 5. Number of seeds in fruit of *Lycium* spp. cultivars and varieties: see Fig. 2

![Cluster dendrogram analyzed on four morphometric parameters of fruits of *Lycium* spp. 21 cultivars and varieties](image)

The Cluster I contained two cultivars Wild (*L. barbarum*) and Amber Sweet (*L. chinense*) only, and these two cultivars differed by the least number of seeds in the fruit. The largest number of samples (18 cultivars and varieties) was included in Cluster II. The Cluster III consisted of the cultivar Delikat (*L. chinense*) which is found to be furthest from all other genotypes Cluster I, II, and differs from other ones by the smallest shape index and fruits length and the largest diameter of the fruits.

**Discussion**

In Ukraine, goji has not been investigated or grown on an industrial commercial scale. Since 2016, the Department of Fruit Plants Acclimatization (M. M. Gryshko National Botanical Garden) has been working on creating a *Lycium* spp. collection. Our collection includes 45 genotypes from seeds or cuttings obtained from China, France, Slovak Republic and other Botanical Gardens of Ukraine. In the selection process 26 promising genotypes of *Lycium* spp were involved, of which 9 candidates were selected for cultivars. Among the studied *L. barbarum* plants a group was identified that differed in features of the structure of flowers and the nature of pubescence of the corolla and petals. According to the description in Flora of China, the plants correspond to the species *L. truncatum* Y. C. Wang. Therefore, such cultivars as Ningqi 1 (N1 Lifeberry), Super Sweet, Korean Big, New Big and Princess Tao have been considered within this species.

Currently, only in China are breeding programs focused mainly on species: *L. barbarum*, *L. chinense* and *L. ruthenicum*. The first selection work started in China at 1960–1970s at the Ningxia Research Center of Wolfberry Engineering Technology (China), which was renamed as National Wolfberry Engineering Research Center in 2011 (Chen et al., 2018). The result of their work is only a few established and used cultivars: Damaye and Ningqi 1 (in Europe known as N1 Lifeberry). As noted by the authorization, breeding work was conducted with *L. barbarum*. In Europe, the largest plantations are laid in Germany, Serbia, Macedonia, Greece, Bulgaria, Spain and Portugal. The cultivation of goji berries in Poland is still developing. There are companies supporting the establishment of plantations. Several companies have also been launched to deal with the purchase and processing of fruit. In Poland, Chinese wolfberry (*L. barbarum*) selection is introduced, mostly based on seeds of this species imported from Tibet and China. Among several types the best rated is NQ 1 and it has been incorporated into nursery production. Bulgarian varieties are also available: JB1, JB2, JBX and JB4. Planting by sowing seeds is also promoted (Marosz, 2017).

Azim et al. (2018) pointed that fruit diameter of barberry is response to different areas revealed a wide range of differences with each other. Mean values of fruit diameter ranged from 6–9 mm in various ecotypes. Kazbekovna et al. (2018) comparing morphological features of *L. barbarum* fruits from the North Caucasus stated that length of fruits ranged from 8 to 18 mm and their diameter from 5 to 10 mm. Commercial goji are
categorized into six grades depending on the number of fruits per 50 g. In the best grade there are 180–200 fruits per 50 g and in the lowest grade 980 fruits (Yao et al., 2018). Chen et al. (2018) stated that the weight of 1000 fruit of valuable varieties such as Dumaya and Nanguqi was 450–510 and 586 g, respectively. Azim et al. (2018) stated that 100 fruit weight was highly significantly positively correlated with fruit diameter and was not significantly positively correlated with plant height, main stem diameter, number of thorns and plant canopy.

Our results have shown that investigated parameters values are similar within those obtained by Wang et al. (2011), Qin et al. (2012a, b), Dai et al. (2015), Yang et al. (2015), and Zhurba (2019) (Table 2).

Table 2

| Authors | Species, cultivars | Fruit weight, g | Fruit length, mm | Fruit diameter, mm |
|---------|--------------------|-----------------|------------------|-------------------|
| Wang et al., 2011 | *Lycium* (cv. Ningqi 6) | 1.29 | 22.73 | 9.29 |
| Qin et al., 2012a | *Lycium* (cv. Ningqi 7) | *=* | 22.0 | 1.18 |
| Qin et al., 2012b | *Lycium* (cv. Ningqi 5) | 1.10 | 25.40 | 17.40 |
| Dai et al., 2015 | *L. barbarum* (cv.Ningqi99) | 1.06 | *=* | *=* |
| Yang et al., 2015 | *Lycium* (cv. Zhongke Luchuan 1) | *=* | 14.20 | 13.60 |
| Zhurba, 2019 | *L. chinense* | 0.81 | 16.13 | 9.35 |
| According to our data | *L. barbarum* | 0.74 | 17.83 | 8.42 |
| to our data | *L. truncatum* | 0.67 | 17.69 | 8.36 |

Note: *=* - no data available.

Conclusions

Plants of the genus *Lycium*, due to their growing importance as functional food, require systematic research work. In the case of food use large fruit size is important. In the results of our research on  *L. barbarum*, *L. chinense* and *L. truncatum*, in terms of fruit sizes for the following genotypes and varieties stand out: LB2, LC Amber Sweet and LT Super Sweet. The collected varieties and genotypes can be the basis for obtaining new varieties distinguished by the size of crops and their quality.

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