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# Morphological and pomological characterization of $F_2$ generation cucumber (*Cucumis sativus* L.) plants of different fruit types

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## Abstract

In general, when the traits related to cucumber breeding are examined, morphological traits such as leaf and flower characteristics, fruit; size, shape, spines, fruit flesh set, as well as yield are among the most important factors among the breeding selection criteria. The morphological and pomological characterization of 109 plants belonging to 16 $F_2$ lines of different fruit types under soilless agriculture conditions were carried out and lines with breeding material value were identified. The average fruit weights of the lines with different fruit types were determined as mini (snack) type 53.88 g, beith alpha type 138.84 g, gherkin type 49.95 g and long european type 194.22 g. The highest fruit flesh firmness was determined as 0.98 kg/cm$^2$ in lines with mini (snack) fruit type, while the lowest was determined as 0.59 kg/cm$^2$ in lines with beith alpha fruit type. Warts on the fruit surface were detected on C355 and N285 lines with gherkin fruit type and C348 line with long european fruit type, while there were without warts on the fruit surfaces of other lines. Beith alpha fruit type, 8 plants of line C350 had monoecious flower structure, while the plants of other lines had gynoic flower structure. The longest internode was 13.75 cm in line N285 and the shortest internode was 8.53 cm in line C350. Differences between lines and plants with different fruit type were determined by principal component analysis. It was determined that there was a wide variation among the plants in terms of all the traits examined and the traits that can be used as breeding material for future studies in cucumber were identified.

**Keywords:** Fruit type, Selection, Warts, Internode, Variation

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## INTRODUCTION

Cucumber is a species of vegetable belonging to the *Cucurbitaceae* family, which is widely cultivated in the world. Cucumber (*Cucumis sativus* L.), whose origin is India, is one of the oldest cultivated vegetable species. Cucumber can be cultivated in tropical and subtropical climatic conditions as well as temperate climatic conditions in terms of climate requirements. Cucumber fruits are fragrant and delicious with a wealth of nutrients that can be consumed fresh, cooked or pickled (Mercke et al., 2004; Zhang et al., 2021). In regions with cold climatic conditions, it is cultivated in open or under greenhouse during the summer months (Robinson & Decker-Walters, 1997; Salcedo et al., 2018). In the world, approximately 94 million tons of cucumber is produced on 2.174.347 ha of land, with China ranking first with 77.258.256 tons, followed by Türkiye (1.938.545 tons) and Russia (1.635.903 tons) (FAO, 2022). Cucumber has an important place in human nutrition. Cucumber regulates the human body's fluid intake, blood pressure and sugar and fat repair, soothes the skin, aids digestion and aids weight loss. Cucumbers contain plenty of potassium, magnesium, manganese and high levels of vitamins A, C and K (Chakraborty & Rayalu, 2021). The immature fruits of cucumber are used fresh or for gherkins. The fruits of the cucumber plant are harvested about two weeks after flowering, depending on the variety. At this stage, the whole fruit is consumed because the fruit texture is crunchy and the seeds are small and not fully ripe (Chakraborty & Rayalu, 2021). Unlike fruits eaten ripe, where metabolic traits such as sweetness, flavor and aroma are the main

quality determinants, the predominant morphological traits that determine cucumber fruit quality are size and shape, external traits such as wax, spines and warts, and internal traits such as flesh thickness and seed cavity size. These morphological characteristics are evident in the different cucumber cultivars grown around the world. East Asian cucumbers consumed fresh are typically North Chinese type (Langa type), North American cucumber types intended for fresh markets are characterized by smooth, medium length (20-30 cm), while North American and European pickling cucumbers have spiny and short fruits (5-15 cm). Beit Alpha or Mediterranean cucumbers have a parthenocarpic structure and thin skin thickness. In parthenocarpic cucumber varieties, fruit formation occurs without pollination. In addition to the dominant market classes, there is a wide diversity in fruit morphology in cucumber genetic material (Grumet et al., 2022). Fruit size is related to both cell number and a combination of cell size. In cucumber fruits, cell number is mainly formed during ovary development, with the second stage of cell division occurring during the first 4-5 days after pollination. Fruit shape is typically elongated and cylindrical in commercially grown cucumbers. However, cucumber fruit vary greatly in several factors that influence shape, including length, diameter, uniformity (cylindrical and conical) and tendency to curl (Wei et al., 2016; Zhu et al., 2016; Gao et al., 2020). The surface shape of cucumber fruits varies according to the presence of the waxy layer, the number, size and shape of ridges and spines. The presence of spines on the fruit surface is a hydrophobic layer that covers the aerial surfaces of plants to limit cuticular water loss; provide mechanical support for fruit growth and development; and protect against environmental stresses such as pathogens, insects, UV radiation and drought (Yang et al., 2014; Grumet et al., 2022). The rind of ripe cucumber fruit can be of various colors such as white-green-yellow-orange-brown. However, the rind color of immature cucumber fruit at the harvest stage has a narrower spectrum than other immature fruits, ranging from white to light green to dark green. Variation in skin color of immature fruit can be a desirable novelty for the market. In fruit flesh color, a narrower range of color is observed in the fruit mesocarp and endocarp. Cucumber fruit flesh is typically white, but can also have yellow, orange and green flesh color. The yellow and orange flesh color is due to the accumulation of carotenoids, including beta-carotene (Zhu et al., 2016; Wang et al., 2020; Grumet et al., 2022). The development of high-yielding varieties with better fruit quality is the main objective of cucumber breeding programs worldwide. The spread of parthenocarpic cucumber varieties in our country and in the world increases cucumber production. Türkiye is rich in plant biodiversity and is a production center for many vegetable species. However, since the origin of cucumber is not Türkiye, the cucumber varieties used in our country were first originated abroad. This process continued with breeding companies bringing new varieties to our country, and then breeding companies in our country developed new hybrid or standard varieties using these varieties. Although there are studies on the characterization of hybrid or local cucumber varieties in our country, there is a need for much more studies. Characterization studies are very important for breeding studies in terms of yield, disease resistance and determination of cucumber types suitable for market demand. In addition, a good identification of the starting material of breeding programs provides great advantages by preventing time and economic loss in the breeding process. Therefore, it is necessary to determine the agronomic and genetic performance of these genetic materials as well as their characterization. The aim of this study was to make a morphological and pomological characterization of 16 $F_2$ cucumber lines and to select lines with breeding material value.

## MATERIALS AND METHODS

### Plant Material

As plant material, $F_2$ plants obtained by selfing in 2023 from cucumber cultivars of different fruit types, which are widely used in greenhouse cultivation in Türkiye, were used.

### Method

The morphological and pomological characterization study was carried out in 2024 in the geothermally heated, venlo type, glass and fully automated R&D greenhouse of Kırşehir Ahi Evran University. Seed sowing was carried out in a 128-cell seedling plug tray filled with a peat:perlite mixture at a 3:1 ratio. Plants were grown in the greenhouse by irrigation and fertilization until the first true leaf stage. When the seedlings reached planting size, they were planted in cocopeat medium with a distance of 25 cm between rows and 100 cm between rows. In the experiment, the number of plants from each $F_2$ line specified in Table 1 was transplanted. Irrigation, fertigation and acclimatization processes (the amount of water and fertilizer was adjusted depending on the plant growth stage and greenhouse temperature) were carried out with an automation system. Since the plants were in $F_2$ generation, the experiment was not set up with replicates. The averages of the measurements and observations were determined according to the number of $F_2$ plants within the lines.

### Examined Parameters

In the experiment, morphological and pomological characterization was carried out in terms of plant and fruit traits according to IPGRI's description list for cucumber and UPOV criteria (Protocol for tests of difference, uniformity and stability, UPOV TG/44/11 Rev.3). The 7 morphologically examined criteria and their criteria are given in Table 2. Fruit measurements were completed when the fruits in the center of the plants were ripe. During the observation and measurement period of the study, the length of the traits to be examined were measured with a ruler, diameter and thickness were measured with calipers, and fruit weight was measured with a balance. Fruit

juice Ec and pH values were measured with Ec meter and pH meter with Extech device. Fruit flesh firmness was measured with PCEPTR 200 penotrometer. Soluble solids content (SSC) was measured with Hanna HI96801 digital refractometer.

Table 1. $F_2$ lines and plant numbers used in the study

| $F_2$ Lines | Number of Plants | $F_2$ Lines | Number of Plants |
|---|---|---|---|
| C323 | 8 | C340 | 3 |
| C343 | 8 | C350 | 8 |
| C290 | 4 | C357 | 8 |
| C333 | 8 | C355 | 4 |
| C336 | 7 | N285 | 4 |
| C339 | 8 | C295 | 8 |
| C304 | 8 | C312 | 7 |
| C307 | 8 | C348 | 8 |
| | | Total | 109 |

Table 2. Morphologically parameters

| No | Observed Characteristics | Scale Values |
|---|---|---|
| 1 | Fruit color | Dark Green, Green, Light Green |
| 2 | Number of fruits per node (Fruit set) | Multi, Semi-Multi, Single |
| 3 | Fruit spine | Present, Light, Absent |
| 4 | Fruit wart | Present Absent |
| 5 | Plant growth | Very Strong, Strong, Medium Strong |
| 6 | Fruit type | Mini (snack), Beith Alpha, Gherkin, Long European Type (LET) |
| 7 | Flower Structure | Monoecious, Gynoic |

**Statistical analysis**

The data obtained in the studies were analyzed by one-way analysis of variance (ANOVA) using SPSS 18.0 statistical software (IBM, Chicago, IL, USA) at 5% significance level and the difference between the means was determined by Duncan multiple comparison test. In addition, principal component analysis (PCA) were performed using Minitab statistical software.

**RESULTS**

The plants in the $F_2$ generation obtained by selfing 16 hybrid cucumber cultivars of different types widely used in greenhouse cultivation were classified according to fruit type. In terms of fruit characteristics, the line averages of average fruit weight, fruit diameter, fruit length, fruit flesh firmness, SCC, EC and pH parameters were determined (Table 3). Among 16 lines, 2 of them were identified as mini (snack), 9 as Beith Alpha, 2 as gherkin and 3 as long european fruit type (Figure 1).


Figure 1. Long European (C-312), Beith Alpha (C-333), Mini (snack) (C-323) and Gherkin (C-355) type cucumber fruits

The average fruit weight of 9 cucumber lines of beith alpha type was 138.84 g. The highest average fruit weight among beith alpha lines was determined as line C-339 with 190.70 g. The average fruit weight of 3 cucumber lines of long european type was 194.22 g, while the line with the highest fruit weight was determined as line C-312 with 243.10 g. The average fruit weight, fruit length and fruit diameter of the lines with 2 mini (snack) and 2 gherkin fruit types were lower than the lines with beith alpha and long european fruit types used in the study. The highest average flesh firmness was measured in the lines with mini (snack) (0.98 kg/cm$^2$) and gherkin (0.78 kg/cm$^2$) fruit types, while the lowest average flesh firmness was determined in the lines with beith alpha fruit type with 0.59 kg/cm$^2$. The highest fruit juice SSC was determined in the lines with mini (snack) fruit type (3.95%), while the lowest SSC was determined in the lines with gherkin fruit type (2.77%). The highest juice Ec value was determined in mini (snack) type lines (2.83) and the lowest in long european type lines (2.47). Fruit juice pH of 16 lines ranged between 6.02 (C-290) and 7.05 (C-390). There was no statistically significant difference between the lines in terms of juice EC, pH, and SSC parameters ($p>0.05$) (Table 3).

Table 3. Average fruit weight, fruit length, fruit flesh firmness, fruit juice SSC, Ec and pH of cucumber lines in $F_2$ generation with different fruit types

| $F_2$ Lines | Fruit Type [mini (snack), beith alpha, gherkin, long european] | Fruit Weight (g) | Fruit Length (cm) | Fruit Width (cm) | Fruit Flesh Hardness kg/cm$^2$ | Soluble Solids Content (SSC) | Fruit Juice Ec | Fruit Juice pH |
|---|---|---|---|---|---|---|---|---|
| C323 | Mini (snack) | 63.83ef | 10.27g | 3.17b-e | 0.86ab | 3.93 | 2.67 | 6.12 |
| C343 | Mini (snack) | 43.93f | 9.97g | 2.53de | 1.09a | 3.97 | 2.98 | 6.15 |
| Average | | 53.88 | 10.12 | 2.85 | 0.98 | 3.95 | 2.83 | 6.14 |
| C290 | Beith Alpha | 121.63b-f | 14.50de | 3.63a-c | 0.67bc | 2.73 | 3.06 | 6.02 |
| C333 | Beith Alpha | 128.90b-e | 16.57c-e | 3.43a-c | 0.68bc | 3.57 | 2.57 | 6.14 |
| C336 | Beith Alpha | 131.80b-e | 15.83c-e | 3.50a-c | 0.68bc | 3.70 | 2.53 | 6.07 |
| C339 | Beith Alpha | 190.70ab | 18.50bc | 3.90ab | 0.46bc | 3.10 | 2.63 | 6.09 |
| C304 | Beith Alpha | 96.33d-f | 13.83ef | 3.33a-d | 0.65bc | 2.77 | 3.00 | 6.11 |
| C307 | Beith Alpha | 108.80c-f | 16.10c-e | 3.03c-e | 0.51bc | 3.17 | 2.97 | 6.82 |
| C340 | Beith Alpha | 170.17a-d | 15.33c-e | 4.03a | 0.36c | 2.83 | 2.87 | 6.46 |
| C350 | Beith Alpha | 126.57b-e | 16.73c-e | 3.50a-c | 0.56bc | 3.17 | 2.70 | 6.05 |
| C357 | Beith Alpha | 174.70a-c | 18.03b-d | 4.10a | 0.71a-c | 3.13 | 2.59 | 6.10 |
| Average | | 138.84 | 16.16 | 3.61 | 0.59 | 3.13 | 2.77 | 6.21 |
| C355 | Gherkin | 45.10f | 10.33fg | 2.37e | 0.79ab | 2.63 | 2.68 | 6.32 |
| N285 | Gherkin | 54.80ef | 10.07g | 3.00c-e | 0.72a-c | 2.90 | 2.46 | 6.33 |
| Average | | 49.95 | 10.20 | 2.69 | 0.76 | 2.77 | 2.57 | 6.33 |
| C295 | Long European | 163.60b-d | 21.53b | 3.43a-c | 0.71a-c | 3.57 | 2.41 | 6.27 |
| C312 | Long European | 243.10a | 26.67a | 3.80a-c | 0.73a-c | 2.90 | 2.47 | 7.05 |
| C348 | Long European | 175.97a-c | 21.33b | 3.60a-c | 0.80ab | 3.50 | 2.54 | 6.38 |
| Average | | 194.22 | 23.18 | 3.61 | 0.75 | 3.32 | 2.47 | 6.57 |
| p value | | *** | *** | *** | *** | n.s. | n.s. | n.s. |

Different letters in the same column indicate that the difference between groups is significant $p < 0.05$. ns, non-significant. * $p < 0.05$, ** $p < 0.01$ and *** $p < 0.001$

Principal component analysis (PCA) was performed to classify the cucumber lines in the $F_2$ generation based on fruit pomological traits (Figure 2). According to the analysis, two principal components (99.90% according to PC1 and 0.09% according to PC2) accounted for 99.99% of the total variation. The lines with the highest fruit length, fruit diameter, fruit weight and fruit juice pH were located in regions I. and IV. of the graph. The lines with long european and Beith Alpha fruit type were all located in regions I. and IV. of the graph. Cucumber lines with mini (snack) and gherkin fruit type were located in the II. and III. regions of the graph. The lines with the highest flesh firmness and SSC were C-343 and C323 with the mini (snack) fruit type, while the lines with the lowest SSC were the lines with the Beith Alpha fruit type, which were located in region IV. of the graph. The lines with the

highest juice Ec were located in region III. of the graph, while the lines with the lowest fruit juice Ec were located in region I. of the graph.

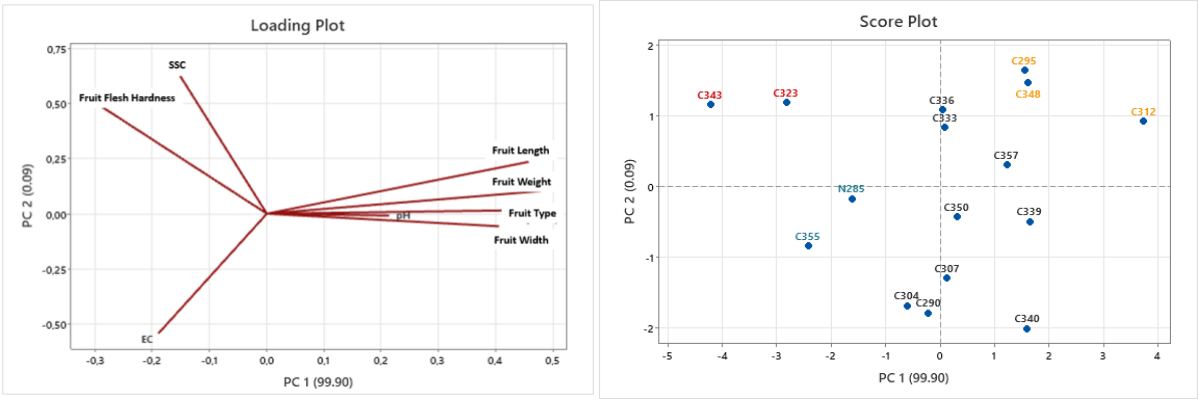


Figure 2. Principal component analysis (PCA) of the average fruit weight, fruit length, fruit flesh firmness, fruit juice SSC, Ec and pH parameters of $F_2$ cucumber lines with different fruit types

As a result of the parameters examined, in terms of fruit color, all plants of the silor fruit type, line C-313 had dark green fruit color, while the plants of line C-343 had green fruit color. $F_2$ plants of line C-323 showed single, semi-multi and single fruit set, while plants of line C-343 had multi and semi-multi fruit set. While the fruits of 16 $F_2$ plants of both lines were spineless, they had strong plant vigor and gynoic flower structure. The difference between the mean internode length of the $F_2$ plants of line C-323 and the mean internode length of the plants of line C-343 was 1.12 cm, while this difference was 2.44 cm in leaf width and 0.45 cm in leaf length (Table 4).

Table 4. Fruit color, fruit set, fruit spine, fruit wart, plant vigor, flower structure, internode length, leaf width and length of mini (snack) type lines

| $F_2$ Code | Fruit Color (Dark Green, Green, Light Green) | Number of fruits per node (Multi, Semi-Multi, Single) | Fruit Spine (Present, Light, Absent) | Fruit wart (Present, Absent) | Plant Growth (Very Strong, Strong, Medium Strong) | Flower Structure (Monoecious, Gynoic) | Internode Length (cm) | Leaf Width (cm) | Leaf Length (cm) |
|---|---|---|---|---|---|---|---|---|---|
| C323-1 | Dark Green | Single | Absent | Absent | Strong | Gynoic | 10.00 | 28.00 | 25.50 |
| C323-2 | Dark Green | Multi | Absent | Absent | Strong | Gynoic | 11.00 | 30.50 | 28.00 |
| C323-3 | Dark Green | Multi | Absent | Absent | Strong | Gynoic | 10.00 | 23.50 | 22.50 |
| C323-4 | Dark Green | Semi Multi | Absent | Absent | Strong | Gynoic | 10.00 | 30.00 | 27.00 |
| C323-5 | Dark Green | Semi Multi | Absent | Absent | Strong | Gynoic | 11.00 | 28.50 | 26.50 |
| C323-6 | Dark Green | Single | Absent | Absent | Strong | Gynoic | 12.00 | 29.50 | 26.00 |
| C323-7 | Dark Green | Semi Multi | Absent | Absent | Strong | Gynoic | 12.00 | 25.50 | 23.50 |
| C323-8 | Dark Green | Semi Multi | Absent | Absent | Strong | Gynoic | 12.00 | 24.50 | 22.50 |
| Average | | | | | | | 11.00 | 27.50 | 25.19 |
| C343-1 | Green | Multi | Absent | Absent | Strong | Gynoic | 12.00 | 31.50 | 24.00 |
| C343-2 | Green | Multi | Absent | Absent | Strong | Gynoic | 9.00 | 27.00 | 26.00 |
| C343-3 | Green | Semi Multi | Absent | Absent | Strong | Gynoic | 9.00 | 29.50 | 26.00 |
| C343-4 | Green | Semi Multi | Absent | Absent | Strong | Gynoic | 9.00 | 36.50 | 27.00 |
| C343-5 | Green | Multi | Absent | Absent | Strong | Gynoic | 10.00 | 34.20 | 25.50 |
| C343-6 | Green | Multi | Absent | Absent | Strong | Gynoic | 11.00 | 27.00 | 27.00 |
| C343-7 | Green | Semi Multi | Absent | Absent | Strong | Gynoic | 9.00 | 27.50 | 24.50 |
| C343-8 | Green | Multi | Absent | Absent | Strong | Gynoic | 10.00 | 26.50 | 25.00 |
| Average | | | | | | | 9.88 | 29.96 | 25.63 |

When the fruit color of 9 $F_2$ lines of Beith Alpha type was evaluated; 3 lines (C-290, C-340, C-357) had dark green, 4 lines (C-333, C-336, C-339, C-307) had green and 2 lines (C-304, C-350) had light green fruit color. While all $F_2$ plants of line C-339 showed multi fruit set, plants of line C-307 had semi-multi fruit set and all plants of line C-340 had single fruit set. The lines were uniform in terms of fruit shape, plant vigor and flower structure. In terms of flower structure, except for the $F_2$ plants belonging to the C-350 line, all other $F_2$ plants had gynoic flower structure. Among the Beith Alpha type lines, the highest average internode length and leaf width were determined in line C-357 with 11.63 cm and 31.09 cm, respectively, while line C-340 had the highest average leaf length with 26.17 cm (Table 5).

Table 5. Fruit color, fruit set, fruit spine, fruit wart, plant vigor, flower structure, internode length, leaf width and length of Beith Alpha type lines

| $F_2$ Code | Fruit Color (Dark Green, Green, Light Green) | Number of fruits per node (Multi, Semi-Multi, Single) | Fruit Spine (Present, Light, Absent) | Fruit wart (Present, Absent) | Plant Growth (Very Strong, Strong, Medium Strong) | Flower Structure (Monoecious, Gynoic) | Internode Length (cm) | Leaf Width (cm) | Leaf Length (cm) |
|---|---|---|---|---|---|---|---|---|---|
| C290-1 | Dark Green | Single | Absent | Absent | Medium Strong | Gynoic | 10.00 | 28.00 | 24.50 |
| C290-2 | Dark Green | Semi Multi | Absent | Absent | Medium Strong | Gynoic | 9.00 | 29.30 | 24.50 |
| C290-3 | Dark Green | Semi Multi | Absent | Absent | Medium Strong | Gynoic | 10.00 | 26.80 | 24.00 |
| C290-4 | Dark Green | Semi Multi | Absent | Absent | Medium Strong | Gynoic | 8.00 | 27.50 | 24.00 |
| Average | | | | | | | 9.25 | 27.90 | 24.25 |
| C333-1 | Green | Semi Multi | Absent | Absent | Very Strong | Gynoic | 8.00 | 26.00 | 23.00 |
| C333-2 | Green | Semi Multi | Absent | Absent | Very Strong | Gynoic | 10.00 | 28.00 | 23.00 |
| C333-3 | Green | Semi Multi | Absent | Absent | Very Strong | Gynoic | 10.00 | 23.70 | 21.10 |
| C333-4 | Green | Semi Multi | Absent | Absent | Very Strong | Gynoic | 8.00 | 26.00 | 22.70 |
| C333-5 | Green | Single | Absent | Absent | Very Strong | Gynoic | 8.00 | 21.20 | 19.80 |
| C333-6 | Green | Semi Multi | Absent | Absent | Very Strong | Gynoic | 10.00 | 23.90 | 21.60 |
| C333-7 | Green | Single | Absent | Absent | Very Strong | Gynoic | 7.00 | 26.40 | 20.00 |
| C333-8 | Green | Single | Absent | Absent | Very Strong | Gynoic | 9.00 | 25.00 | 22.00 |
| Average | | | | | | | 8.75 | 25.03 | 21.65 |
| C336-1 | Green | Multi | Light | Absent | Medium Strong | Gynoic | 11.00 | 26.00 | 24.50 |
| C336-2 | Green | Multi | Light | Absent | Medium Strong | Gynoic | 12.00 | 29.50 | 25.50 |
| C336-3 | Green | Multi | Light | Absent | Medium Strong | Gynoic | 10.00 | 23.50 | 24.00 |
| C336-4 | Green | Semi Multi | Light | Absent | Medium Strong | Gynoic | 8.00 | 24.50 | 23.00 |
| C336-5 | Green | Multi | Light | Absent | Medium Strong | Gynoic | 11.00 | 26.50 | 26.50 |
| C336-6 | Green | Semi Multi | Light | Absent | Medium Strong | Gynoic | 9.00 | 31.00 | 25.00 |
| C336-7 | Green | Semi Multi | Light | Absent | Medium Strong | Gynoic | 13.00 | 32.00 | 28.50 |
| Average | | | | | | | 10.57 | 27.57 | 25.29 |
| C339-1 | Green | Multi | Light | Absent | Strong | Gynoic | 11.00 | 25.00 | 23.00 |
| C339-2 | Green | Multi | Light | Absent | Strong | Gynoic | 11.00 | 25.50 | 23.50 |
| C339-3 | Green | Multi | Light | Absent | Strong | Gynoic | 11.00 | 25.00 | 21.50 |
| C339-4 | Green | Multi | Light | Absent | Strong | Gynoic | 10.00 | 26.50 | 25.00 |
| C339-5 | Green | Multi | Light | Absent | Strong | Gynoic | 9.00 | 22.50 | 28.80 |
| C339-6 | Green | Multi | Light | Absent | Strong | Gynoic | 9.00 | 25.50 | 27.00 |
| C339-7 | Green | Multi | Light | Absent | Strong | Gynoic | 9.00 | 28.00 | 24.50 |
| C339-8 | Green | Multi | Light | Absent | Strong | Gynoic | 9.00 | 32.00 | 20.20 |
| Average | | | | | | | 9.88 | 26.25 | 24.19 |

| $F_2$ Code | Fruit Color (Dark Green, Green, Light Green) | Number of fruits per node (Multi, Semi-Multi, Single) | Fruit Spine (Present, Light, Absent) | Fruit wart (Present, Absent) | Plant Growth (Very Strong, Strong, Medium Strong) | Flower Structure (Monoecious, Gynoic) | Internode Length (cm) | Leaf Width (cm) | Leaf Length (cm) |
|---|---|---|---|---|---|---|---|---|---|
| C304-1 | Light Green | Single | Absent | Absent | Strong | Gynoic | 12.00 | 24.50 | 21.00 |
| C304-2 | Light Green | Semi Multi | Absent | Absent | Strong | Gynoic | 9.00 | 29.00 | 24.50 |
| C304-3 | Light Green | Semi Multi | Absent | Absent | Strong | Gynoic | 8.00 | 33.00 | 28.00 |
| C304-4 | Light Green | Single | Absent | Absent | Strong | Gynoic | 9.00 | 31.00 | 27.00 |
| C304-5 | Light Green | Semi Multi | Absent | Absent | Strong | Gynoic | 8.00 | 21.50 | 21.00 |
| C304-6 | Light Green | Single | Absent | Absent | Strong | Gynoic | 8.00 | 29.00 | 27.00 |
| C304-7 | Light Green | Semi Multi | Absent | Absent | Strong | Gynoic | 8.00 | 28.50 | 26.00 |
| C304-8 | Light Green | Semi Multi | Absent | Absent | Strong | Gynoic | 8.00 | 29.70 | 27.50 |
| Average | | | | | | | 8.75 | 28.28 | 25.25 |
| C307-1 | Green | Semi Multi | Absent | Absent | Strong | Gynoic | 11.00 | 31.00 | 27.00 |
| C307-2 | Green | Semi Multi | Absent | Absent | Strong | Gynoic | 11.00 | 30.70 | 27.00 |
| C307-3 | Green | Semi Multi | Absent | Absent | Strong | Gynoic | 11.00 | 25.50 | 24.00 |
| C307-4 | Green | Semi Multi | Absent | Absent | Strong | Gynoic | 12.00 | 28.00 | 24.50 |
| C307-5 | Green | Semi Multi | Absent | Absent | Strong | Gynoic | 11.00 | 28.50 | 24.50 |
| C307-6 | Green | Semi Multi | Absent | Absent | Strong | Gynoic | 9.00 | 28.70 | 25.50 |
| C307-7 | Green | Semi Multi | Absent | Absent | Strong | Gynoic | 11.00 | 26.00 | 24.00 |
| C307-8 | Green | Semi Multi | Absent | Absent | Strong | Gynoic | 11.00 | 27.00 | 23.70 |
| Average | | | | | | | 10.88 | 28.18 | 25.03 |
| C340-1 | Dark Green | Single | Absent | Absent | Very Strong | Gynoic | 11.00 | 30.00 | 26.00 |
| C340-2 | Dark Green | Single | Absent | Absent | Very Strong | Gynoic | 11.00 | 30.00 | 27.00 |
| C340-3 | Dark Green | Single | Absent | Absent | Very Strong | Gynoic | 10.00 | 30.50 | 25.50 |
| Average | | | | | | | 10.67 | 30.17 | 26.17 |
| C350-1 | Light Green | Single | Absent | Absent | Very Strong | Monoecious | 9.00 | 27.40 | 25.00 |
| C350-2 | Light Green | Semi Multi | Absent | Absent | Very Strong | Monoecious | 10.00 | 27.70 | 25.00 |
| C350-3 | Light Green | Semi Multi | Absent | Absent | Very Strong | Monoecious | 9.00 | 28.90 | 25.40 |
| C350-4 | Light Green | Semi Multi | Absent | Absent | Very Strong | Monoecious | 7.00 | 29.00 | 25.60 |
| C350-5 | Light Green | Semi Multi | Absent | Absent | Very Strong | Monoecious | 9.00 | 22.30 | 21.00 |
| C350-6 | Light Green | Semi Multi | Absent | Absent | Very Strong | Monoecious | 10.00 | 29.20 | 28.00 |
| C350-7 | Light Green | Multi | Absent | Absent | Very Strong | Monoecious | 7.00 | 28.00 | 27.00 |
| C350-8 | Light Green | Semi Multi | Absent | Absent | Very Strong | Monoecious | 8.00 | 28.00 | 25.00 |
| Average | | | | | | | 8.63 | 27.56 | 25.25 |

| $F_2$ Code | Fruit Color (Dark Green, Green, Light Green) | Number of fruits per node (Multi, Semi-Multi, Single) | Fruit Spine (Present, Light, Absent) | Fruit wart (Present, Absent) | Plant Growth (Very Strong, Strong, Medium Strong) | Flower Structure (Monoecious, Gynoic) | Internode Length (cm) | Leaf Width (cm) | Leaf Length (cm) |
|---|---|---|---|---|---|---|---|---|---|
| C357-1 | Dark Green | Multi | Absent | Absent | Medium Strong | Gynoic | 12.00 | 32.00 | 26.00 |
| C357-2 | Dark Green | Semi Multi | Absent | Absent | Medium Strong | Gynoic | 12.00 | 34.50 | 27.60 |
| C357-3 | Dark Green | Multi | Absent | Absent | Medium Strong | Gynoic | 10.00 | 35.00 | 27.00 |
| C357-4 | Dark Green | Multi | Absent | Absent | Medium Strong | Gynoic | 14.00 | 31.80 | 27.20 |
| C357-5 | Dark Green | Multi | Absent | Absent | Medium Strong | Gynoic | 10.00 | 29.60 | 22.00 |
| C357-6 | Dark Green | Multi | Absent | Absent | Medium Strong | Gynoic | 10.00 | 30.00 | 27.90 |
| C357-7 | Dark Green | Multi | Absent | Absent | Medium Strong | Gynoic | 13.00 | 25.90 | 22.60 |
| C357-8 | Dark Green | Multi | Absent | Absent | Medium Strong | Gynoic | 12.00 | 29.90 | 26.00 |
| Average | | | | | | | 11.63 | 31.09 | 25.79 |

Among the lines with gherkin fruit type, all $F_2$ plants of line C-355 had dark green fruit color, semi-multi fruit set, warty and spiny fruit, strong plant growth and gynoic flower structure, while $F_2$ plants of line N-285 had green leaf color, multi fruit set, spiny fruit set, strong plant growth and gynoic flower structure. The average internode length of $F_2$ plants of line N-285 was (1.5 cm) longer, leaf width (1.5 cm) shorter and leaf length (0.90 cm) longer than line C-355 (Table 6).

Table 6. Fruit color, fruit set, fruit spine, fruit wart, plant vigor, flower structure, internode length, leaf width and length of Gherkin type lines

| $F_2$ Code | Fruit Color (Dark Green, Green, Light Green) | Number of fruits per node (Multi, Semi-Multi, Single) | Fruit Spine (Present, Light, Absent) | Fruit wart (Present, Absent) | Plant Growth (Very Strong, Strong, Medium Strong) | Flower Structure (Monoecious, Gynoic) | Internode Length (cm) | Leaf Width (cm) | Leaf Length (cm) |
|---|---|---|---|---|---|---|---|---|---|
| C355-1 | Dark Green | Semi Multi | Present | Present | Strong | Gynoic | 11.00 | 24.00 | 17.90 |
| C355-2 | Dark Green | Semi Multi | Present | Present | Strong | Gynoic | 15.00 | 30.20 | 25.30 |
| C355-3 | Dark Green | Semi Multi | Present | Present | Strong | Gynoic | 12.00 | 29.10 | 23.70 |
| C355-4 | Dark Green | Semi Multi | Present | Present | Strong | Gynoic | 11.00 | 35.10 | 29.20 |
| Average | | | | | | | 12.25 | 29.60 | 24.03 |
| N285-1 | Green | Multi | Present | Present | Very Strong | Gynoic | 13.00 | 28.40 | 29.40 |
| N285-2 | Green | Multi | Present | Present | Very Strong | Gynoic | 13.00 | 26.10 | 20.70 |
| N285-3 | Green | Multi | Present | Present | Very Strong | Gynoic | 16.00 | 32.00 | 26.80 |
| N285-4 | Green | Multi | Present | Present | Very Strong | Gynoic | 13.00 | 25.90 | 22.80 |
| Average | | | | | | | 13.75 | 28.10 | 24.93 |

The fruit color of all $F_2$ plants belonging to 3 lines with Long European type fruit was found to be dark green. While uniformity was observed in lines C-295 and C-312 in terms of fruit set, single fruit set was observed in 8 $F_2$ plants of line C-348. While ribless fruit shape and very strong plant growth were observed in $F_2$ plants of lines C-

395 and C-312, warty and spiny fruit shape and strong plant growth were observed in plants of line C-348. While the plants of line C-312 had monoic flower structure, the plants of the other two lines had gynoic flower structure. The longest internode length and leaf width averages were obtained from the plants of line C-312, while the longest leaf average was obtained from the plants of line C-295 (Table 7).

Table 7. Fruit color, fruit set, fruit spine, fruit wart, plant vigor, flower structure, internode length, leaf width and length of Long European type lines

| $F_2$ Code | Fruit color (Dark Green, Green, Light Green) | Number of fruits per node (Multi, Semi-Multi, Single) | Fruit Spine (Present, Light, Absent) | Fruit wart (Present, Absent) | Plant Growth (Very Strong, Strong, Medium Strong) | Flower Structure (Monoecious, Gynoic) | Internode Length (cm) | Leaf Width (cm) | Leaf Length (cm) |
|---|---|---|---|---|---|---|---|---|---|
| C295-1 | Dark | Semi Multi | Absent | Absent | Very Strong | Gynoic | 9.00 | 28.50 | 28.30 |
| C295-2 | Dark | Semi Multi | Absent | Absent | Very Strong | Gynoic | 10.00 | 26.00 | 24.50 |
| C295-3 | Dark | Semi Multi | Absent | Absent | Very Strong | Gynoic | 10.00 | 32.10 | 28.60 |
| C295-4 | Dark | Semi Multi | Absent | Absent | Very Strong | Gynoic | 9.00 | 34.30 | 30.10 |
| C295-5 | Dark | Single | Absent | Absent | Very Strong | Gynoic | 8.00 | 30.00 | 28.40 |
| C295-6 | Dark | Single | Absent | Absent | Very Strong | Gynoic | 9.00 | 24.50 | 23.00 |
| C295-7 | Dark | Semi Multi | Absent | Absent | Very Strong | Gynoic | 9.00 | 27.80 | 26.00 |
| C295-8 | Dark | Semi Multi | Absent | Absent | Very Strong | Gynoic | 9.00 | 31.00 | 27.70 |
| Average | | | | | | | 9.13 | 29.28 | 27.08 |
| C312-1 | Dark | Semi Multi | Absent | Absent | Very Strong | Monoecious | 14.00 | 32.10 | 28.60 |
| C312-2 | Dark | Semi Multi | Absent | Absent | Very Strong | Monoecious | 12.00 | 26.50 | 24.60 |
| C312-3 | Dark | Semi Multi | Absent | Absent | Very Strong | Monoecious | 10.00 | 32.40 | 29.10 |
| C312-4 | Dark | Semi Multi | Absent | Absent | Very Strong | Monoecious | 10.00 | 31.30 | 16.80 |
| C312-5 | Dark | Single | Absent | Absent | Very Strong | Monoecious | 12.00 | 37.10 | 30.00 |
| C312-6 | Dark | Single | Absent | Absent | Very Strong | Monoecious | 9.00 | 36.00 | 30.50 |
| C312-7 | Dark | Single | Absent | Absent | Very Strong | Monoecious | 10.00 | 18.60 | 18.00 |
| Average | | | | | | | 11.00 | 30.57 | 25.37 |
| C348-1 | Dark | Single | Present | Present | Strong | Gynoic | 12.00 | 23.00 | 17.00 |
| C348-2 | Dark | Single | Present | Present | Strong | Gynoic | 11.00 | 21.00 | 16.00 |
| C348-3 | Dark | Single | Present | Present | Strong | Gynoic | 11.00 | 27.10 | 16.40 |
| C348-4 | Dark | Single | Present | Present | Strong | Gynoic | 11.00 | 25.00 | 20.40 |
| C348-5 | Dark | Single | Present | Present | Strong | Gynoic | 10.00 | 23.80 | 24.60 |
| C348-6 | Dark | Single | Present | Present | Strong | Gynoic | 11.00 | 28.10 | 23.30 |
| C348-7 | Dark | Single | Present | Present | Strong | Gynoic | 10.00 | 24.20 | 26.40 |
| C348-8 | Dark | Single | Present | Present | Strong | Gynoic | 10.00 | 22.00 | 18.20 |
| Average | | | | | | | 10.75 | 24.28 | 20.29 |

Principal component analysis (PCA) was performed to classify $F_2$ plants based on fruit color, fruit set, fruit shape, plant growth, fruit type, flower structure and fruit color of 109 cucumber plants with different fruit types (Figure 3). According to the analysis, two principal components (68.52% according to PC1 and 14.37% according to PC2) accounted for about 83% of the total variation. $F_2$ plants with gynoic flower structure, medium strong plant growth and long internodes were mostly located in regions I. and IV. of the graph, while plants with light green fruit color, monoic flower structure, single fruit set and spine fruit shape were mostly located in regions II. and III. of the graph. Plants with high leaf width and length are located in the III. and IV. region of the graph. Plants with multi fruit set and spine fruit shape were mostly located in regions I and IV of the graph. 109 $F_2$ plants obtained by selfing 16 $F_2$ lines with different fruit types were located in 4 regions of the graph. The positioning of the plants in different regions shows that there is a wide variation among $F_2$ plants in terms of the parameters examined.

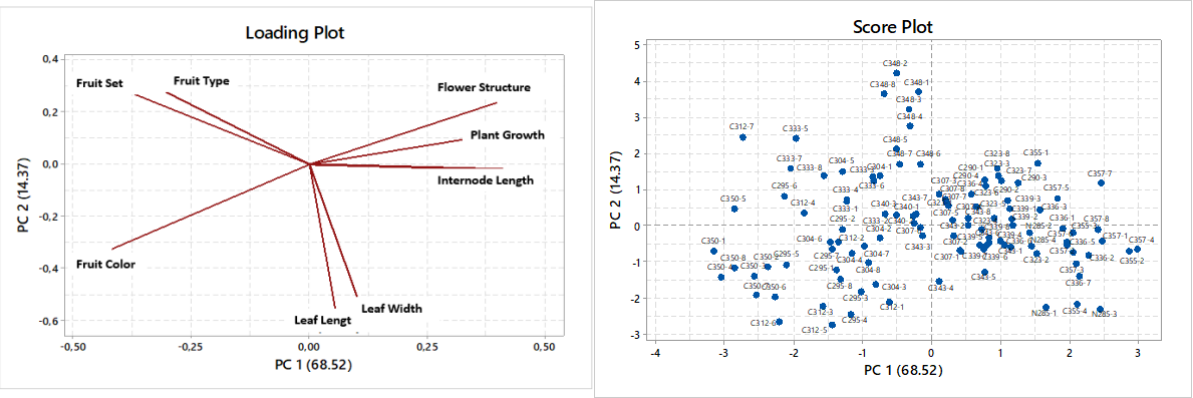


Figure 3. PCA graph of morphological and pomological characteristics of $F_2$ cucumber lines with different fruit types

## DISCUSSION

Many different cucumber varieties with different fruit characteristics such as shape and texture are being studying by breeders to meet consumers demands. For many years, many cucumber varieties with different fruit characteristics have been developed in different parts of the world. İn cucumber breeding programs, the characteristics of the starting material need to be fully characterized. Identification in the gene pool is done by characterization studies. Plant characterization means the identification of the available genetic material. Morphological or agronomic characterization is carried out to transfer inherited traits. The data collected during characterization is considered very useful as it helps to easily distinguish one genetic material from another and also helps to identify genotypes and lines with important traits. This study, morphological and agronomic characterization studies were carried out on 16 hybrid lines at $F_2$ generation. In terms of fruit type, it was determined that 9 lines of Beith Alpha, 3 lines of Long European, 2 lines of gherkin and 2 lines of Mini (snack) had fruit type. While fruit weight and fruit length of Beith Alpha and Long European type cucumber lines were higher than silor and gherkin type lines, there was not much difference between the types in terms of fruit diameter parameter. Shimomura et al., (2017) reported that cucumber genotypes with different fruit length and weight had no statistical difference in fruit diameter. In parallel with our results, Grumet et al., (2022) reported that parthenocarpic, greenhouse-grown cucumber types with long fruits ranged between 20-40 cm and those with short fruits between 12-15 cm. Kumar et. al., (2013) completed a characterization study on thirty-two cucumber genotypes showed that there was a wide variation among genotypes in terms of average fruit weight, powdery mildew tolerance and aphid damage. Fruit size and shape, especially fruit length, were important fruit characteristics during cucumber domestication and varietal selection (Zhang et al., 2021).Fruit flesh firmness in cucumber is important for the preservation of fruit quality in storage and transportation. Especially since mini (snack) and gherkin type cucumber genotypes are used in pickling and in order to preserve the crispness of the pickle, the fruit flesh firmness should be high. In our study, mini (snack) and gherkin type cucumber lines had the highest fruit flesh firmness. The fruit color of the cucumber lines used in the study varied from light green to dark green. Especially the different fruit color variation in each fruit type will be able to meet the desired fruit color demand for the market in the coming years. Compared to light green skinned fruits, dark skinned fruits have a higher number of chloroplasts and higher levels of chlorophyll a, chlorophyll b and carotenoids. Dark green fruit skins have higher flavonoid and anthocyanin content as well as greater antioxidant activity (Bo et al., 2012; Miao et al., 2019; Jo et al., 2022).

In our study, one of the cucumber lines of long european type cucumber had a spiny fruit surface, while two of them did not have spines on the fruit surface. Both of the gherkin type cucumber lines had spiny fruit surfaces. Fruit surfaces of Beith Alpha and mini (snack) type lines were without warts. Fruit skin characteristics such as spine size and color, fruit warts, dull and uniform color are some of the most important external quality characteristics, along with size and shape, which determine commercial types. All these characteristics are related to the market value of cucumber (Koyama, 1986; Valcárcel et al., 2018). Western fresh market cucumber is generally smooth at harvest, while the western pickling type has a surface with sparse, rounded spines. Northern Chinese cucumbers have large, broad warts covering the fruit surface. Fruits with smoother surfaces are increasingly preferred for commercial production, as the presence of warts and spines can interfere with packing and processing of the fruit (Grumet et al., 2022). Since gherkin-type cucumbers are used in pickling, the high number of surface spines causes the fruit peel to thicken and this contributes to the preservation of pickle quality during the pickle processing process by increasing the hardness of the fruit flesh. In our study, while monoic or gynoic flower structure was observed in each fruit type, having lines with these two flower structures is important both during breeding and for increasing yield and fruit quality, especially gynoic cucumber genotypes form parthenocarpic fruits.

## CONCLUSION

As a result of the characterization study, since there is a wide variation among the $F_2$ plants in terms of the traits examined in each fruit type, the genetic material we have can constitute the starting material for future breeding studies. In addition, the identification of these traits of the lines in the early period, in the $F_2$ generation and recording these traits will prevent the loss of traits in the later generations and the identification of the genetic factors controlling these traits in future studies will facilitate the breeder's work in terms of less time, labor and financial support in increasing yield and quality, improving transportation, handling and storage characteristics and developing varieties with the quality desired by the consumer.

**Compliance with Ethical Standards**

**Peer-review**

Externally peer-reviewed.

**Conflict of interest**

The authors state there is no competing interest.

**Author contribution**

Authors' individual contributions to the article are equal.

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