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The Effects of Shading on Some Agronomical Traits of The Tea Plants (*Camellia sinensis* (L.) Kuntze)

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Abstract

This research was conducted to determine the effect of different shading leves on some agronomical traits of the tea plant (*Camellia sinensis* (L.) Kuntze) in 2024. The study was carried out during the first shoot period of tea and shading nets were used at different densities (Control, 35%, 55% and 75%) to reduce sunlight transmittance. In the study, shoot length (cm), number of leaves per shoot (unit), leaf length (cm), leaf width (cm), leaf color, fresh leaf yield (g m^{-2}), dry matter content (%), total polyphenol (%), and caffeine rate (%) were examined in tea plants. As a result of the study, it was determined that the shoot length and the dry matter rate were not affected by shading, but other examined traits showed statistically significant ($P<0.01$) changes depending on the shading rate. The highest values in terms of leaf length, leaf width and leaf color values were obtained from the control and 35% shading rates, while the number of leaves per shoot was reached the maximum at 75% shading. As the shading rate increased, the number of leaves per shoot also increased, while the fresh leaf yield tended to decrease. At 75% shading rate, total polyphenol and caffeine levels were at the highest level, and the decreasing the shading rate led to a decrease in the values belonging to these quality elements.

Keywords: *Camellia sinensis,* Shading, Quality, Leaf.

Gölgelemenin Çay (*Camellia sinensis* (L.) Kuntze) Bitkisinin Bazı Agronomik Özellikleri Üzerindeki Etkileri

Öz

Bu araştırma, farklı gölgeleme düzeylerinin çay bitkisinin (*Camellia sinensis* (L.) Kuntze) bazı tarımsal özellikleri üzerine etkisini belirlemek amacıyla 2024 yılında yürütülmüştür. Çalışma, çayın ilk sürgün döneminde gerçekleştirilmiş ve güneş ışığı geçirgenliğini azaltmak için farklı yoğunluklarda (Kontrol, %35, %55 ve %75) gölgeleme ağları kullanılmıştır. Çalışmada çay bitkilerinde sürgün uzunluğu (cm), sürgün başına yaprak sayısı (adet), yaprak uzunluğu (cm), yaprak genişliği (cm), yaprak rengi, taze yaprak verimi (g m^{-2}) ve kuru madde içeriği (%), toplam polifenol (%) ve kafein oranı (%) incelenmiştir. Çalışma sonucunda sürgün uzunluğu ve kuru madde oranının gölgelemeden etkilenmediği; ancak incelenen diğer özelliklerin gölgeleme oranına bağlı olarak istatistiksel olarak önemli ($P<0.01$) düzeyde değişim gösterdiği belirlenmiştir. Yaprak uzunluğu, genişliği ve renk değerleri kontrol ve %35 gölgeleme oranlarında en yüksek düzeyde bulunurken, sürgün başına yaprak sayısı %75 gölgelemede maksimuma ulaşmıştır. Gölgeleme oranı arttıkça, sürgün başına düşen yaprak sayısı artarken, taze yaprak verimi azalma eğilimi göstermiştir. %75 gölgeleme oranında, toplam polifenol ve kafein seviyeleri en yüksek seviyede gerçekleşmiş olup, gölgeleme oranının azalması bu kalite unsurlarına ait değerlerin azalmasına yol açmıştır.

Anahtar Kelimeler: *Camellia sinensis*, Gölgeleme, Kalite, Yaprak.

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1. Introduction

Tea is a perennial plant belonging to the *Camellia* genus of the Theaceae family (Caffin et al., 2004). The dryness of the final product obtained by processing tea leaves has made it possible to store the product easily and consume it at any time, which is effective in making it a daily beverage. Tea is grown in very limited areas due to the plant's special climate requirements. The countries having the highest tea production are China, India, Kenya, Sri Lanka, Türkiye, and Viet Nam, respectively (URL-1, 2024). Tea cultivation is carried out in a total of 5 provinces in Türkiye, primarily in Rize (AEPDI, 2023).

Climate and soil factors are the most important factors affecting the growth of the plant. For tea cultivation, the annual average temperature should be at least 14 °C, the total annual rainfall should be at least 2000 mm and the distribution of rainfall should be regular to the months, the relative humidity should be at least 70% and the soil should have an acid reaction (Kacar, 2010).

In order to obtain high quality tea products, it is very important to carry out the maintenance operations in tea plantations correctly and to carry out the harvest at the appropriate time (Aaqil et al., 2023; Piyasena and Hettiarachchi, 2023). On the other hand, different methods can be used for specific products. Shading is one of the important methods applied by many growers in the world for different purposes and has many advantages. Shading is an effective method to protect the plants from climatic factors such as temperature and precipitation, as well as insects and similar harmful threats. Differences occur in the morphology, physiology and biochemistry of growing plants under the effect of shade (Zaman et al., 2022).

Shading has important effects on physiological properties of tea, including chlorophyll synthesis, photosynthetic capacity, carbon, nitrogen content, antioxidant activities and secondary metabolites in leaves (Xu et al., 2020). Under shading conditions, some changes in endogenous phytohormones (auxin, cytokinin and gibberellins) play an important role in modulating chlorophyll biosynthesis of the tea leaves (Liu et al., 2020). Pre-harvest shading increases the chlorophyll content by promoting chloroplast development. This method used in tea cultivation is a common process for the production of high-quality tea (Zhang et al., 2014).

Matcha tea, a beverage rich in antioxidant compounds and increasingly popular all over the World. It is a finely ground or powdered form of green tea produced in shade conditions and has a unique characteristic (Jakubczyk et al., 2020). Since sunlight affects the composition and amount of catechins in tea leaves, growing plants away from direct sunlight is effective in producing higher quality teas (Weiss and Anderton, 2003).

Shading process improves the synthesis and accumulation processes of plants during the growth period. It is reported that polyphenolic components such as epicatechin (EC), epicatechin-3-gallate (ECG), epigallocatechin (EGC) and epigallocatechin-3-gallate (EGCG), which are the four main catechins of green tea, increase with shading processes; at the same time, there are increases in the amount of caffeine and rutin, a polyphenolic compound (Jakubczyk et al., 2020).

The effects of shading could vary depending on the genetic structure and ecological conditions. In this context, there is no detailed shading treatment conducted on tea plants in Türkiye. In this study, the effect of different shading rates on tea was determined.

2. Material and Method

This research was conducted in a tea plantation area in Rize/Türkiye (41°01'30"N latitude, 40°32'48"E longitude) in 2024. The trial area was established 60-70 years ago. It is located at an altitude of 216 m and 1 km from the sea. Plants with similar height, canopy diameter and shoot density were selected to ensure uniformity among plots. Each plot consisted of 5 tea bushes. The plots were covered during 25 days with a shading net with the ability to block sunlight at 35%, 55% and 75% while the control plots were left open. At the end of the period, on 31.05.2024, fresh shoots were harvested as 3,5 leaves (Savsatli et al., 2021; Salman et al., 2022) and the leaf samples were taken for laboratory analysis.

2.1. Climate Characteristics

According to long-term climate data for Rize province, the dormant period begins from the month when the harvest period ends. The dormant period covers the months of December, January, February and March, and the average temperatures belonging to these months remains below 10 ºC. In April, which is the beginning of the shoot growth period, the average temperature rises to 15.7 ºC. The shoots reach a sufficient size for harvest with the weather warming up in May. Long-term average climate data show that Rize province has a very suitable climate for tea cultivation. In 2024, when the study was conducted, the average temperature belonging to May was 16.2 ºC, and the lowest daily average temperature was 9.1 ºC and the number of cloudy days was 18 days in the same month (Table 1).

Table 1. Climate data for the tea growing period of Rize province in 2024 (URL-2, 2024)

Meteorological Data/Months	March	April	May	June	March
Monthly Average Temperature (ºC)	10.1	15.7	16.2	23.4	18.4
Highest Temperature (Cº)	21.5	31.8	24.3	31.1	29.1
Lowest Temperature (ºC)	4.4	8.9	9.1	14.6	10.8
Monthly Average Relative Humidity (%)	78.1	74.6	82.2	74.2	77
Monthly Total Sunshine Duration (hours)	133.2	170.2	154.1	224.2	182.8
Monthly Number of Rainy Days (days)	16	11	21	12	14
Number of Clear Days (days)	4	6	3	1	3
Number of Cloudy Days (days)	14	15	18	12	15

2.2. Soil Properties

The soil analysis results show that the soil of the experimental area contains enough nitrogen and phosphorus, and the soil pH (5.15) is suitable for tea cultivation. No fertilizer application was made considering the soil analysis data.

2.3. Examined Traits

In the study, fresh leaf yield (g m^{-2}), shoot length (cm), number of leaves in the shoot (unit), leaf length (cm), leaf width (cm) and leaf color measurements, leaf dry matter (%), total polyphenol (%) and caffeine (%) analyses were made. The leaf samples taken from the plots were dried in the oven at 40 °C, and ground until they became powder and then placed in zip-lock bags and stored in the refrigerator at +4 °C for total polyphenol and caffeine analyses.

2.4. Leaf Color

After the leaf samples dried in the freeze dryer (Labconco brand) were turned into powder, measurements were made with the Chorma Meter CR-400 device and the leaf color was determined in terms of L* lightness value (L*=0 black color, L*=100 white color), a* value (+a red, -a green color) and b* value (+b yellow, -b blue color).

2.5. Total Polyphenol and Caffeine Analysis

Total polyphenol analysis in tea samples was performed according to ISO 14502-2 (ISO, 2005). It was performed according to the 'Determination of Caffeine' method specified in the International Trade Centre-United Nations Confederation on Trade and Development, (UNCTAD, 1982).

2.6. Statistical Analysis

The experiment was conducted in randomized block design with 3 replications. All statistical analyses were performed using the JMP version 5.0.1 (Software Program-2006, SAS Institute Inc., Cary, NC). The means of the examined traits were calculated with standard error values. The statistical analysis of significance was performed at significance level $P<0.05$. TUKEY Multiple Comparison Test was applied to compare the means. Hierarchical cluster analysis was performed by using the SPSS 20.0 Software, Fix Pack 1.

3. Results and Discussion

In this study, the findings and statistical analysis results of the features discussed are presented in Table 2, and the changes in investigated traits depending on shading levels are given in the Fig. 1 and Fig. 2.

Table 2. Mean values and standard errors belonging to the examined traits depending on the shading level

	Shading rate					
Traits	**Control**	**35%**	**55%**	**75%**	**CV%**	**$F_{Calc.}$**
Fresh leaf yield (g m-^{2})	170±34.64^a	116±20.21^{ab}	86±8.08^{ab}	69±6.93^b	31.7	4.82**
Dry matter (%)	32.67±0.62	31.56±0.25	30.66±0.54	29.81±0.77	3.4	3.94
Total polyphenol (%)	11.63±0.39^c	11.88±0.32^c	12.83±0.38^b	13.80±0.16^a	1.9	53.37**
Caffeine (%)	3.72±0.08^b	3.82±0.05^b	3.88±0.08^b	4.24±0.07^a	3.1	10.76**
Shoot length (cm)	19.06±2.79	18.18±0.88	15.36±0.84	13.92±1.40	18.8	1.75
Num. of leaves on shoot (unit)	4.9±0.09^d	6.0±0.12^c	6.7±1.60^b	7.9±0.09^a	3.1	136.87**
Leaf width (cm)	3.87±0.23^a	3.24±0.17^{ab}	3.06±0.13^b	2.81±0.09^b	7.7	9.73**
Leaf length (cm)	8.45±0.23^a	8.11±0.17^{ab}	7.69±0.13^b	7.06±0.09^c	2.0	42.54**

**$P<0.01$, There is no statistical difference between the values expressed with the same letter.

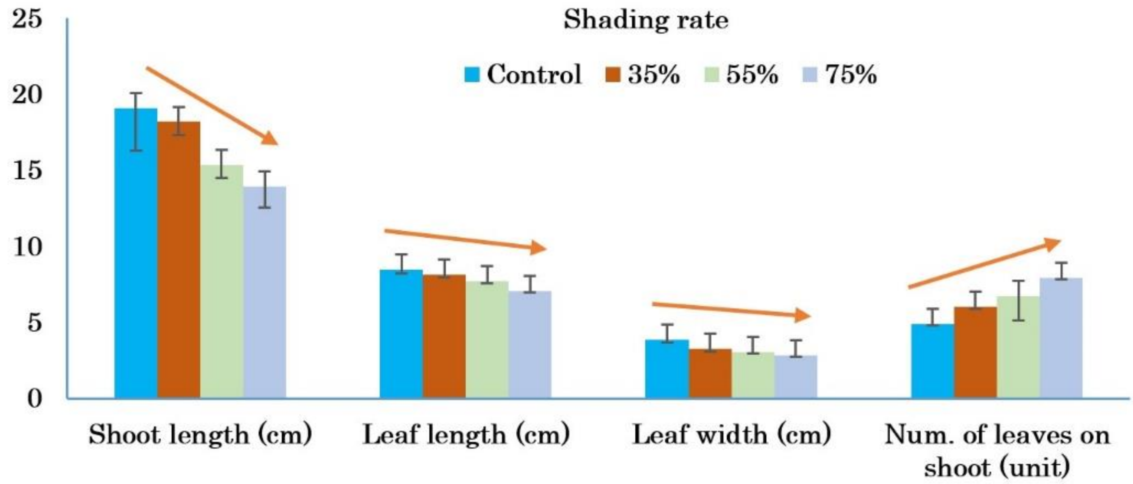

Figure 1. Effects of shading levels on shoot and leaf traits of tea plant. Values represent mean ± SE (n = 3). Statistical significance was determined using Tukey's HSD test (P < 0.05).

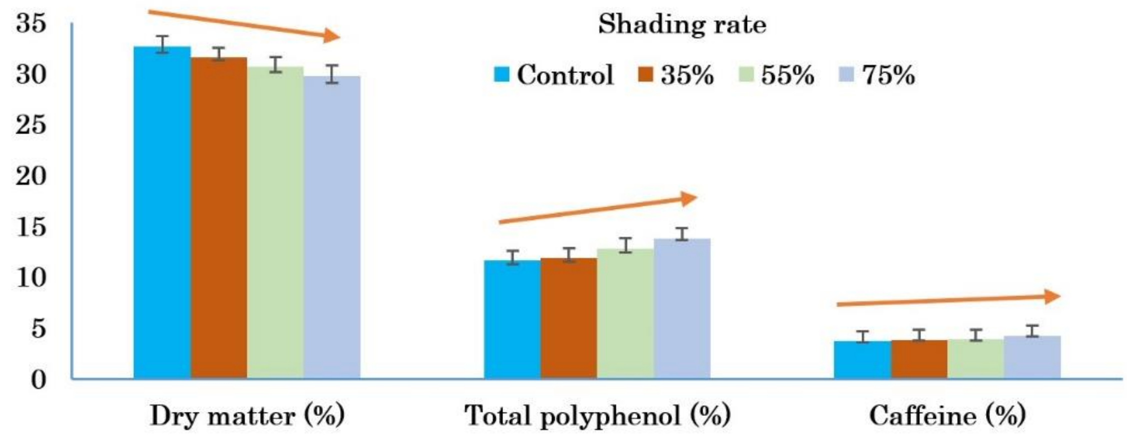

Figure 2. Effects of shading levels on quality parameters. Values represent mean ± SE (n = 3). Statistical significance was determined using Tukey's HSD test ($P < 0.05$).

3.1. Dry Matter (%)

Depending on the shading rates, the control ranked first in terms of dry matter rates of fresh tea leaves; it was followed by 35%, 55% and 75% shading rates, respectively. As the shading rate increased, the dry matter rate decreased, but the effect of shading was found to be statistically insignificant (Table 2). In a study conducted by Dale et al. (1972) on barley plants, shading caused a temporary decrease in the dry matter rate, but after two weeks it reached a similar value to that of the control plants.

3.2. Total Polyphenol (%)

Tea leaves contain very beneficial phenolic compounds for health. These compounds vary in amount depending on the shading conditions of the plants (Zhang et al., 2022). In the current study, very significant (P<0.01) differences were found between the total polyphenol values of the leaves depending on the shading rate (Table 2). The highest total polyphenol value was determined in the 75% shading level. As the shading rate decreased, total polyphenol values also decreased. The catechins found in abundance in tea have an important place among the polyphenols. These valuable compounds can improve stress resistance in plants (Chobot et al., 2009). In a shading study conducted by Sano et al. (2018), EGC contents showed significant differences. Gallate-type catechins (ECG and EGCG) had significantly higher values compared to the unshaded area. Similarly, as a result of 12-day shading application on tea plants by Fernie et al. (2004), (+)-Catechin, (-)-Epicatechin, Epigallocatechin gallate, kaempferol, rutin and some flavonols tended to increase under shading.

3.3. Caffeine (%)

Having a stimulating effect, caffeine is an important component of the tea leaves (Kacar, 2010). In the present study, the shading had a significant (P<0.01) effect on the caffeine content in the leaves (Table 2). The highest caffeine content was obtained at 75% shading level. Other shading levels were in the same statistical group. It was stated that shading method increased the caffeine content of tea leaves (Kimura and Kanda, 2013; Sano et al., 2018). This method allows the plant to produce high amounts of bioactive compounds, including chlorophyll and L-theanine. Therefore, the products with high theanine and caffeine content can be obtained with shading (Kimura and Kanda, 2013).

3.4. Number of Leaves on Shoot (unit)

The highest number of leaves per shoot was obtained from 75% shading rate (P<0.01) (Table 2). As the shading rate decreased, the number of leaves also decreased; the lowest number of leaves occurred in the control group. Similar results were obtained in a study conducted on Artemisia stolonifera. The shading increased number of leaves and chlorophyll content in A. stolonifera (Li et al., 2022). Depending on shading levels, natural physical changes occured in plants.

3.5. Shoot Length (cm)

Control group ranked first in terms of shoot length, followed by 35%, 55% and 75% of shading rates, respectively (Table 2). Shoot length tended to decrease as shading rates increased, but the differences between the shading rates were found to be statistically insignificant. Kausar et al. (2022) found that internodes shortened under intense shading. In the present study, the fact that shading did not affect shoot length but caused an increase in the number of leaves could be related to the shortening of internodes.

3.6. Leaf Width (cm)

Leaf width showed significant ($P<0.01$) differences under varying shading intensities (Table 2). The highest values in terms of leaf width were measured in the control group and at 35% shading rate; in addition, leaf width tended to decrease as the shading rate increased (Li et al., 2022). It is reported that leaf area and photosynthetic content change significantly with the decrease of light intensity during plant development (Senger, 2008). Similarly, Kausar et al. (2022) stated that the physical properties of tea plants changed under shade; plants under intense shading had small and hard leaves.

3.7. Leaf Length (cm)

It was determined that the values of leaf length differed across different shading levels and this difference was significant ($P<0.01$) (Table 2). The lowest leaf length on the new shoot was measured at 75% shading rate. As the shading rate decreased, the leaf length gradually increased. Fan et al. (2016) examined some morphological, growth and physiological characteristics of *Epilobium fangii* and showed that light, moderate and heavy of shading conditions had a significant effect on the leaf length and chlorophyll content of plants.

3.8. Leaf Color

In general, as the shading rate increased, the leaf color measurement values (L*, a* and b*) decreased and a tendency towards dark green color was realized (Table 3). Ma et al. (2024) reported that the formation of dark green leaves could be due to higher chlorophyll pigment content in leaves. Senger (2008) stated that leaf color would change significantly with decreasing light intensity during plant development. The chlorophyll content of the tea leaves increases significantly under shading, shading contributes significantly to leaf coloration and depending on morphology, shading supports chloroplast density and plastid development in tea leaves (Ye et al., 2023). Similarly, Kika et al. (2024) found that the lightness value of matcha tea grown under high shading conditions was lower than that of matcha tea without shade or with lower shade.

Table 3. Leaf color measurement values (as L* a* b*)

Color values	Shading rate			
	Control	35%	55%	75%
*L**	54.05	54.99	53.19	52.42
*a**	-10.42	-11.02	-10.57	-10.62
*b**	27.34	27.29	25.08	24.79

3.9. Hierarchical clustering of shading rates considering the studied traits

The clustering of shading rates based on the 8 traits was performed using the hierarchical clustering Ward method. The results of the dendrogram showed the formation of two separate clusters (Fig. 3). One of these clusters was separated into two sub-clusters, wherein one of the subgroups consisted of 55% and 75% shading. The other subgroup only consisted of 35% shading. The second cluster formed one subcluster. In the subgroup, control group was found alone. 55% and 75% shading had highly similar traits in the cluster. Finally, a total of 3 clusters were formed, namely, A, B and C identified at cutting point 3. Cluster analysis was performed to reveal the relationships between shading rates in the tea plant.

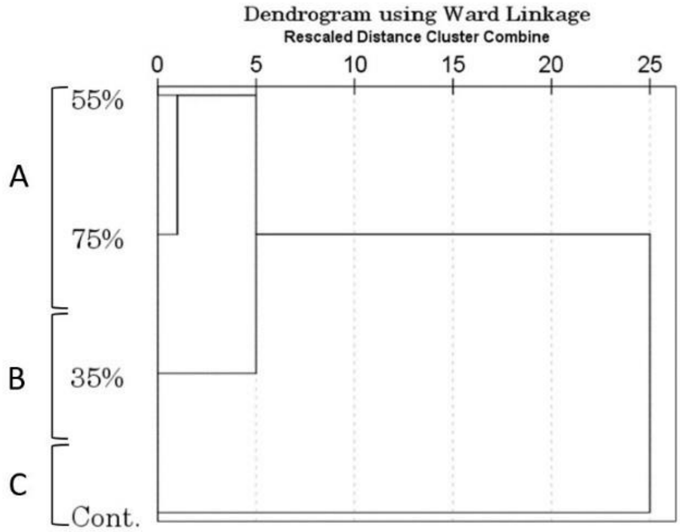

Figure 3. Hierarchical clustering dendrogram of shading treatments. Three clusters (A–C) were identified.

3.10. Principal Component Analysis

The PCA analysis identified two principal components with eigenvalue > 1 (Table 4, Fig. 4). The first principal component was mainly represented by the all the traits except a* color value and explained 81.8% of the total variance. The second principal component was represented by the a* color value and explained 15.8% of the total variance.

Table 4. Eigenvalues, contribution rates, and cumulative variance contribution of the two principal components.

Principal component	Rotation Sums of Squared Loadings		
	Eigenvalues	Contribution rates (%)	Cumulative variance contribution (%)
1	9.0	81.8	81.8
2	1.7	15.8	97.6

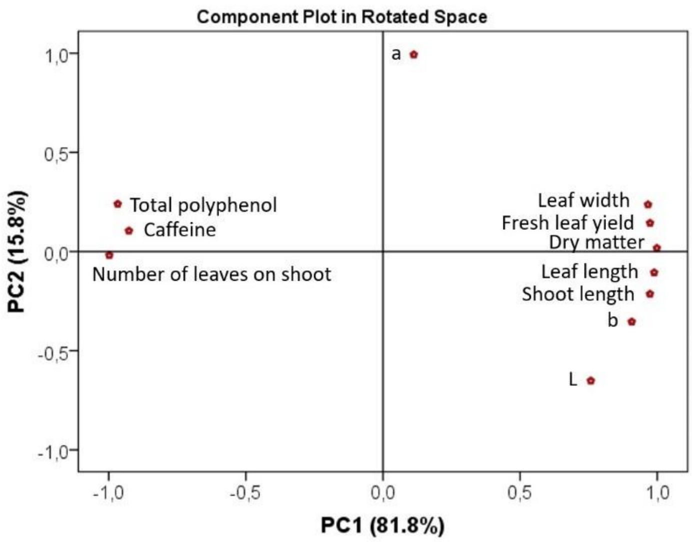

Figure 4. Principal component analysis belonging to the studied traits. L*, a* and b* represent leaf color measurement values.

4. Conclusion

In this study, while the herbal characteristics that will positively affect the yield tend to decrease depending on the shading rate, increases in the shading rate provided a significant increase in the total polyphenol and caffeine values in the tea leaves. It can be suggested to use the shading method in obtaining specific tea products, considering the total polyphenol and caffeine values that play an important role in tea quality.

Author Contribution

Mete, D.: Ideation and Concept, Design, Data Collection and Literature Review. Şavşatlı, Y.: Consulting, Data Processing, Writing and Critical Review

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Conflict of Interest Statement

The authors declare no conflict of interest.

Ethical Standards

An Ethics Committee Decision is not required for this study.

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