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Note

Determination of physical, mechanical, and structural seed properties of pepper cultivars

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A b s t r a c t. The aim of the present study was to determine various physical, mechanical, and structural characteristics of seed of pepper cultivars Yağlık Kapya, Demre Sivri, Yalova Carliston, Kandil Dolma, and Cin Sus Yediveren, which are grown extensively in Turkey, with initial moisture content ranging between 7.03 and 7.21% (w.b.). Width, length, and thickness were found to be in the range of 3.00-3.72, 3.43-4.40, and 0.66-0.82 mm, respectively. It was revealed that sphericity of the seeds of Yağlık Kapya, Demre Sivri, Yalova Carliston, Kandil Dolma, and Cin Sus Yediveren were 51, 57, 56, 51 and 57%, respectively. In terms of the roundness which ranges between 76 and 85% depending on pepper cultivars. The aspect ratio of Yağlık Kapya, Demre Sivri, Yalova Carliston, Kandil Dolma, and Cin Sus Yediveren were determined to be 84.60, 88.04, 94.43, 85.55, and 87.67%, respectively. It was also noted that the porosity of the pepper seeds was in the range of 44.94-49.61%. Besides, we found that as the weight of pepper seeds increased, their terminal velocity increased accordingly, and thus terminal velocities were found to be 2.87-4.66 m s^{-1}. In the current study, the static friction angle and coefficients of the cultivars were determined by means of six different plates including aluminium, stainless steel, galvanized iron, rubber, glass, and plywood. The plywood plate was found to be the least slippery; consequently, the static friction angle and coefficient were determined to be the highest for the plywood plate.

K e y w o r d s: frictional properties, genetic resources, structural properties, pepper cultivars, physical properties

INTRODUCTION

Peppers (*Capsicum* spp.), which are commonly grown and used in Turkey as vegetables and spices, belong to the family *Solanaceae* and provide several essential nutrients (Bae *et al*., 2012). The antioxidant activity of pepper extracts involves bioactive compounds, such as polyphenols, carotenoids, capsaicinoids, and ascorbic acid (Alvarez-Parrilla *et al*., 2010; Hervert-Hernandez *et al*., 2010; Jeong *et al*., 2011).

Estimation of the genetic diversity of genetic resources and determination of the relationships between germplasm collections may also increase the efficiency of efforts to improve a new species (Bozokalfa *et al*., 2009; Köksal *et al*., 2007). However, morphological characterization is the first step in the description and classification of genetic materials. Seeds are vehicles for plant genetic resources, stores of valuable genetic and morphologic information, and expression of biodiversity. Therefore, determination of seed properties is very important for the classification of genetic materials.

Determination of physical and mechanical properties of plant species and cultivars is important to attain successful results in several fields such as plant breeding, packaging, storing (Üçer *et al*., 2010), engineering, consuming, designing and manufacturing of agricultural machinery such as harvesters, transporter machines, seed drill machines, selecting, sizing, and elevating machines, and food processing such as drying, cooling, and freezing (Abdulah *et al*., 2011; Alibas and Koksal, 2012; Balasubramanian *et al*., 2012; Davies, 2010). Seed properties should be considered in breeding studies based on mechanization (Abeels, 1994; Alibas and Koksal, 2012).

In recent years, many researchers have reported physical and mechanical properties of various types of seeds. These include psyllium, lentil, coriander, dragonhead, and hemp seeds (Ahmadi *et al*., 2012; Bagherpour *et al*., 2010; Balasubramanian *et al*., 2012; Dziki *et al*., 2013; Taheri-Garavand *et al*., 2012, respectively).

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This study investigated some physical, mechanical and structural properties of five pepper cultivars (Yağlık Kapya, Yalova Carliston, Cin Sus Yediveren, Sivri Demre, and Kandil Dolma), which are grown commonly in Turkey; in addition, similarities and differences were identified between these cultivars.

MATERIAL AND METHODS

For the study of pepper seed properties: Yağlık Kapya, Demre Sivri, Yalova Carliston, Kandil Dolma, and Cin Sus Yediveren cultivars were used. The seeds were produced in Turkey in 2011. The study was conducted in 2012. In order to measure width (W), length (L), and thickness (T), a digital caliper (Mitutoyo, USA) with 0.01 m sensitivity was used. In order to calculate the geometric mean diameter (D), the three principal dimensions were used as described by Abdullah *et al*. (2011). The roundness and sphericity values were calculated according to Alibas and Koksal (2012). The aspect ratio (R) and surface area (A) of the seed was calculated according to Avira *et al*. (1999) and Abdullah *et al*. (2011).

The angle of repose (*RA*) was calculated with the equation below (Alibas and Koksal, 2012):

$$RA = \tan^{-1}\left(\frac{T_r}{r_r}\right), \quad (1)$$

where: *RA* – angle of repose (°), T_b – height of repose (mm), r_b – mean radius of repose base (mm).

Abdullah *et al*. (2011) described that the volume for 100 seeds was determined using the water displacement method. In order to prevent water absorption, the seeds were weighed and coated with water resistant glue and allowed to dry. Each seed was lowered into a water-containing measuring cylinder such that the seed did not float during immersion in water. The weight of water relocated by the seed was recorded. The ratio of mass to volume of the seed was calculated as true density. The bulk density is defined as the ratio of the mass of the seed sample to its total volume. According to Yalçın (2007), the bulk density was determined by filling an empty 250 ml cylindrical container with the seeds of the pepper cultivars. The seeds were poured from a constant height, striking off the top level and weighted.

The porosity of the pepper cultivar seeds was calculated from bulk and true densities according to Garnayak *et al*. (2008) and Üçer *et al*. (2010).

A flatbed scanner (Scanjet 3770, Hewlett-Packard Comp. Palo Alto, California) with a resolution of 1200 dpi combined with a special programme (Üçer *et al*., 2010; Yalçın, 2007) was used to measure the projected area of seeds.

The terminal velocities of seeds were measured using a cylindrical air column (Yalçın, 2007; Üçer *et al*., 2010). For each experiment, the sample was dropped into the air stream from the top of the air column, up which air was blown to suspend the material in the air stream. The air velocity near the location of the seed suspension was measured by a hot wire anemometer having a least count of 0.01 m s^{-1}.

The initial moisture content of the seeds was determined by oven drying at 105 ± 1°C for 24 h according to Üçer *et al*. (2010) and Alibas and Koksal (2012).

The mineral matter content was determined according to Alibas and Koksal (2012):

$$\%\text{organic} = \frac{HKT - FKT}{FKT}100, \quad (2)$$

$$\%\text{mineral} = 100 - \%\text{organic}, \quad (3)$$

where: *HKT* – air-dry weight (g), *FKT* – oven-dry weight (g), %organic – amount of organic substance within biological material (%), %mineral – amount of mineral substance within biological material.

Five grams of the dried products were added to 200 ml distilled water in a 400 ml flask beaker and the samples were kept at 25°C for 24 h. After rehydration, the samples were taken out, residual water was removed, and adhering water was absorbed carefully with tissue paper and then weighed (Alibas, 2012). The rehydration capacity (R_C) was calculated as follows:

$$R_C = \frac{W_r}{W_d}, \quad (4)$$

where: W_r is the weight after rehydration (kg) and W_d is the weight of dried material (kg).

The germination percentage (GP) was calculated according to Gairola *et al*. (2011).

In determination of static friction angles of the seeds, we used a system that is sensitive towards slipping and shows the angle where pepper seeds begin to slip with a protractor scale. Static friction angles were measured on 6 different surfaces composed of aluminium, stainless steel, galvanized sheet metal, rubber, glass, and MDF materials (İzli *et al*., 2009; Alibas and Koksal, 2012). The coefficient of friction was calculated according to İzli *et al*. (2009).

Data were subjected to ANOVA and means were separated using the LSD test at $p \leq 0.05$. All statistical analyzes were performed using JMP software packages. The study was arranged with three replications and each replication comprised one hundred seeds.

RESULTS AND DISCUSSION

Some physical, mechanical, and structural properties of five pepper cultivars used in the study are given in Table 1. According to Table 1, the width of Cin Sus Yediveren which is 3.00 mm significantly lower than that of all the other seed cultivars. Comparison of the differences in length among the cultivars showed that Yağlık Kapya has the highest value of 4.40 mm. The length of Cin Sus Yediveren, which is the smallest cultivar, is by 22% lower than the length of Yağlık Kapya seeds. No statistically significant difference was found for the thickness of the seeds of the pepper cultivars. Demre Sivri is a cultivar with the

thickest seeds, 0.82 mm, while Cin Sus Yediveren is characterized by the thinnest seeds 0.66 mm. The results of the measurements of the seed width, length, and thickness are similar to those reported by Üçer *et al*. (2010). According to Üçer *et al*. (2010), the length, width, and thickness of red pepper seeds with 7.27% moisture were found to be 4.46, 3.66, and 0.79 mm, respectively.

The length of Yağlık Kapya, Demre Sivri, Yalova Carliston, Kandil Dolma, and Cin Sus Yediveren seeds is greater than their width approximately by 18, 13, 6, 17, and 14%, respectively. Üçer *et al*. (2011) found that the length value was higher than the width value by approximately 22% for red pepper seeds. In the current study, the decrease in the difference between the length and width caused an increase in the aspect ratio, roundness, and sphericity.

The geometric mean diameter of Yağlık Kapya seeds, 2.25 mm, has been found to be the highest. The lowest geometric mean diameter (1.96 mm) was found for Cin Sus Yediveren pepper seeds; it was by 13% lower than that of Yağlık Kapya seeds. The geometric mean diameters of six different hybrid corn seeds were found to differ from one another by Babić *et al*. (2013).

Demre Sivri and Cin Sus Yediveren have the highest sphericity at the rate of 57%. Yağlık Kapya and Kandil Dolma cultivars exhibited the lowest sphericity, by 11% lower than in cultivars with the highest sphericity. Similar results were also obtained by Üçer *et al*. (2011), who found the sphericity of red pepper seeds to be 0.525.

The smallest surface area (12.2 mm^2) was found for the Cin Sus Yediveren seeds. On the other hand, the surface area of the Yağlık Kapya seeds, which have the biggest values, was by 32% larger than that in Cin Sus Yediveren.

Cin Sus Yediveren has the lowest mass of 1000 grains 4.10 g. Yalova Carliston, Kandil Dolma, Demre Sivri, and Yağlık Kapya have 1.33, 1,35, 1,49, and 1.85-fold greater mass of 1000 grains than Cin Sus Yediveren. According to Üçer *et al*. (2010), the mass of thousand grains of red pepper is 7.97 g. This is by 5% higher than Yağlık Kapya, which had the highest mass of thousand grains in our study.

Of all the pepper cultivars, Yağlık Kapya has the highest volume – 7.926 mm^3, whereas the lowest volume rate was found in Cin Sus Yediveren. The difference between the highest and the lowest volume is approximately 34%.

In terms of true and bulk density, the highest values of 956.52 and 505.11 kg m^{-3} were obtained, respectively, in Yağlık Kapya. True and bulk densities of Cin Sus Yediveren are by 18 and 21% lower, respectively, than those in Yağlık Kapya. It was determined that the bulk density of Yağlık Kapya, Demre Sivri, Yalova Carliston, Kandil Dolma, and Cin Sus Yediveren were by nearly 89, 92, 82, 82.5, and 98.5% higher in comparison to their true density.

The decrease in the difference between true and bulk density leads to a decline in porosity; *vice versa*, porosity increases as the difference between true and bulk increases. In terms of porosity, Cin Sus Yediveren has the highest value at the rate of 49.61%. The porosity of Demre Sivri, Yağlık Kapya, Kandil Dolma, and Yalova Carliston seeds was determined to be by 3.41, 4.87, 8.95, and 9.41% lower, respectively, than that of Cin Sus Yediveren seeds. Cin Sus Yediveren, whose weight and dimensional properties (L, W, T) are the lowest, have the highest porosity, compared to the other pepper cultivars. In our study, the porosity of five different pepper cultivars ranged between 45.17 and 49.61%. According to Üçer *et al*. (2010), the porosity of red pepper seeds is 49.43%.

In terms of the angle of repose which ranges between 21.09 and 35.45° depending on pepper cultivars, the difference between the smallest angle (Cin Sus Yediveren) and the biggest angle (Yağlık Kapya) is approximately 40.5%.

Cin Sus Yediveren has the lowest terminal velocity of 2.87 m s^{-1}. Furthermore, the terminal velocity of Demre Sivri, Kandil Dolma, Yalova Carliston, and Yağlık Kapya were found to be 1.32, 1.36, 1.46, and 1.62 times higher than that of Cin Sus Yediveren, respectively. A relationship was found between the terminal velocity and weight. This means that as the weight increases, the terminal velocity increases. Besides, the terminal velocity of red pepper seeds was found to be 4.36 m s^{-1} by Üçer *et al*. (2011). On the other hand, in our study, the terminal velocity values of Yağlık Kapya and Demre Sivri were 4.66 and 4.19 m s^{-1}, respectively, whereas in such cultivars as Cin Sus Yediveren, which are smaller, the terminal velocity decreased.

Comparison of Cin Sus Yediveren, which has the smallest value, and Yağlık Kapya with the largest value in terms of projected area demonstrated a 33% difference between the two cultivars. The projected area of chili seeds was 8.40 mm^2 as determined by Üçer *et al*. (2011), whereas, in our study, the projected area of Yağlık Kapya pepper was found to be 8.31 mm^2, which is closer to this value.

The moisture contents of all cultivars have been found between 7.03 and 7.21%; moreover, there was no significant difference among the cultivars in terms of the moisture content. Üçer *et al*. (2010) found some mechanical and physical properties of red pepper seeds and they estimated the moisture content at 7.27%.

In terms of the mineral matter content, Yağlık Kapya has the highest value of 2.33%. The mineral matter content of Cin Sus Yediveren, which has the lowest value, was 1.13 times lower than that in Yağlık Kapya.

Kandil Dolma was found to have the highest rehydration capacity at the rate of 2.25%. The rehydration capacity rates of Demre Sivri, Yalova Carliston, Cin Sus Yediveren, and Yağlık Kapya are, respectively, 1.22, 1.20, 1.15 and

T a b l e 1. Seed dimensional and structural properties of pepper (*Capsicum annuum*) cultivars

Soil properties	Cultivars				
	Yağlık Kapya	Demre Sivri	Yalova Carliston	Kandil Dolma	Cin Sus Yediveren
Width* (mm)	3.72±0.08a	3.43±0.10a	3.67±0.09a	3.64±0.09a	3.00±0.15b
Length** (mm)	4.40±0.05a	3.89±0.03c	3.89±0.05c	4.26±0.05b	3.43±0.02d
Thickness^{ns} (mm)	0.69±0.05	0.82±0.07	0.71±0.02	0.66±0.04	0.74±0.02
Geometric mean diameter* (mm)	2.25±0.06a	2.22±0.04a	2.16±0.03a	2.17±0.06a	1.96±0.03b
Sphericity*	0.51±0.02b	0.57±0.01a	0.56±0.01a	0.51±0.02b	0.57±0.01a
Roundness^{ns}	0.83±0.01	0.77±0.04	0.85±0.01	0.84±0.01	0.76±0.03
Aspect ratio^{ns} (%)	84.60±1.42	88.04±2.61	94.43±2.51	85.55±3.04	87.67±4.76
Surface area* (mm^2)	15.90±0.91a	15.48±0.56a	14.72±0.42a	14.83±0.79a	12.12±0.42b
Mass of 1000 seeds** (g)	7.58±0.07a	6.10±0.04b	5.44±0.06c	5.52±0.02c	4.10±0.03d
Volume of 10 seeds** (mm^3)	79.29±0.94a	63.94±0.65b	64.34±1.10b	63.98±0.21b	52.27±0.72c
True density** (kg m^{-3})	956.52±3.55a	953.68±5.49a	845.24±8.65b	862.35±4.74b	785.24±8.38c
Bulk density** (kg m^{-3})	505.11±5.75a	496.67±1.67a	465.35±5.11b	472.73±4.55b	395.75±6.79c
Porosity** (%)	47.19±0.75b	47.92±0.19b	44.94±0.22c	45.17±0.82c	49.61±0.33a
Angle of repose** (°)	35.45±0.90a	22.70±2.12b	21.55±0.95b	21.49±0.89b	21.09±2.23b
Terminal velocity** (m s^{-1})	4.66±0.08a	4.19±0.09b	3.80±0.10c	3.89±0.08c	2.87±0.07d
Projected area** (mm^2)	8.31±0.03a	6.89±0.09d	7.51±0.09c	8.04±0.07b	5.55±0.05e
Moisture contentns initial (% w.b.)	7.21±0.03	7.17±0.02	7.10±0.04	7.08±0.05	7.03±0.08
Mineral matter content** (%)	2.33±0.05a	2.20±0.03ab	2.12±0.04bc	2.01±0.02cd	1.89±0.11d
Rehydration capacity** (%)	2.00±0.05b	1.85±0.05c	1.88±0.04bc	2.25±0.03a	1.95±0.07bc
Germination percentage^{ns} (%)	93.67±1.20	95.00±1.73	95.00±1.15	94.67±1.45	95.33±0.88
L/W^{ns}	1.18±0.02	1.14±0.03	1.06±0.03	1.17±0.04	1.15±0.06
L/T*	6.40±0.46a	4.79±0.40b	5.47±0.19ab	6.49±0.46a	4.65±0.12b
L/D*	1.96±0.06a	1.76±0.03b	1.80±0.04b	1.96±0.07a	1.75±0.03b

Values in lines followed by the different letters are statistically different at *p<0.05, ** p<0.01, ns – not significant (LSD).

1.13 times lower than in Kandil Dolma. The germination rates were found to exceed 90% in all cultivars and no statistically significant difference was found among the cultivars.

The frictional properties of five pepper cultivars used in the study are given in Table 2 and Fig. 1 together with statistical differences. According to Table 2, the static friction angle and coefficient of Yalova Carliston on the aluminium plate (25.17 and 0.47°, respectively) were found to be the lowest of all the cultivars. On the other hand, it was found that Cin Sus Yediveren, which is smallest cultivar, had the highest static friction angle and coefficient (50.33 and 1.21°, respectively) on the plywood plate. Comparison of their static friction angles and coefficients showed that the difference between the lowest and the highest value was 2 and 2.57 times, respectively. According to Fig. 1 the static friction angles and coefficients friction on plywood plate were found as the highest value for each of the

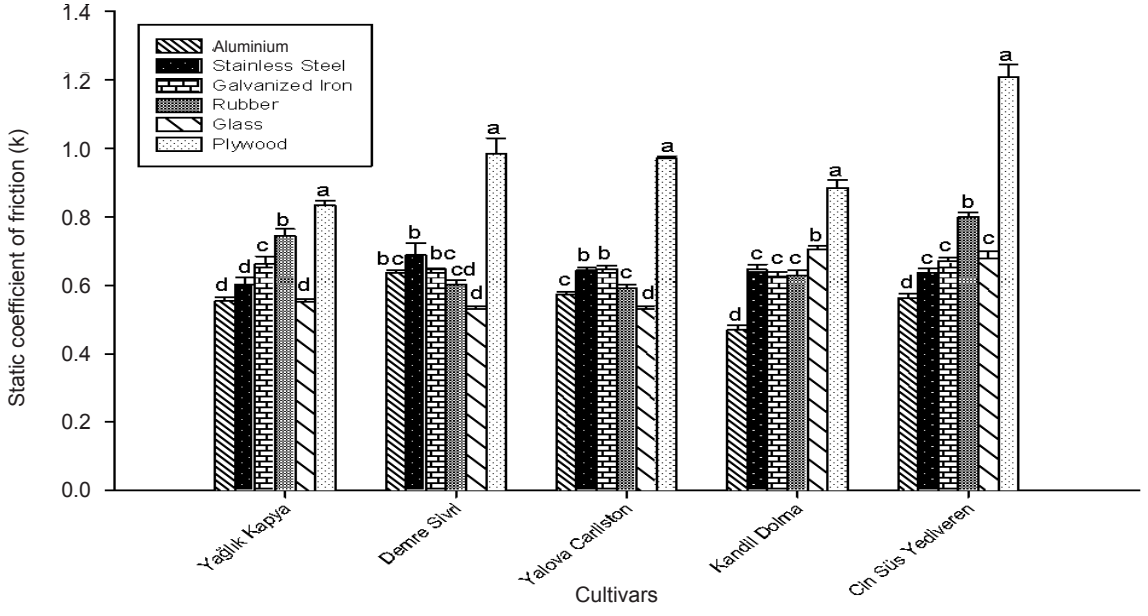

Fig. 1. The static friction coefficient of pepper cultivars depending on the plates used. Values in the group of bars followed by the different letters are statistically different at **p<0.01 (LSD). LSD has been calculated separately for each of the pepper cultivars.

T a b l e 2. Seed frictional properties of pepper (*Capsicum annuum*) cultivars

Soil properties	Cultivars				
	Yağlık Kapya	Demre Sivri	Yalova Carliston	Kandil Dolma	Cin Sus Yediveren
	Static friction angle (°)				
Aluminium**	29.00±0.50b	32.42±0.36a	29.83±0.30b	25.17±0.60c	29.33±0.60b
Stainless steel^{ns}	31.00±0.87	34.50±1.38	32.75±0.38	32.83±0.60	32.50±0.50
Galvanized iron^{ns}	33.50±0.87	32.92±0.08	32.92±0.36	32.00±0.58	33.83±0.44
Rubber**	36.67±0.73b	31.08±0.46c	30.58±0.46c	32.17±0.60c	38.67±0.44a
Glass**	28.83±0.44b	28.00±0.29b	28.00±0.29b	35.17±0.44a	34.17±0.83a
Plywood**	39.83±0.44c	44.50±1.32b	44.17±0.17b	41.50±0.76c	50.33±0.88a
	Static coefficient of friction (k)				
Aluminium**	0.554±0.011b	0.635±0.009a	0.574±0.007b	0.470±0.013c	0.562±0.014b
Stainless steel^{ns}	0.601±0.021	0.689±0.036	0.643±0.009	0.646±0.015	0.637±0.012
Galvanized iron^{ns}	0.662±0.022	0.647±0.002	0.647±0.009	0.625±0.014	0.670±0.111
Rubber**	0.745±0.020b	0.603±0.011c	0.591±0.011c	0.629±0.015c	0.800±0.013a
Glass**	0.551±0.010b	0.532±0.007b	0.532±0.007b	0.705±0.012a	0.679±0.021a
Plywood**	0.834±0.013d	0.985±0.045b	0.971±0.006bc	0.885±0.024cd	1.207±0.038a

Explanations as in Table 1.

pepper cultivars Üçer *et al*. (2010) determined static friction coefficients of red pepper seeds to be 0.394, 0.255, 0.298, and 0.319 using four different rubber, aluminium, stainless steel, and galvanized iron plates.

CONCLUSIONS

1. The physical, mechanical, and structural properties of five pepper cultivars: Yağlık Kapya, Demre Sivri, Yalova Carliston, Kandil Dolma, and Cin Sus Yediveren were determined. It was found that in terms of seed width and length, Yağlık Kapya exhibited the highest values of 3.72 and 4.40 mm, respectively, whereas Cin Sus Yediveren had the smallest values of 3.00 and 3.43 mm.

2. The highest rates of seed roundness and aspect ratio were found in the Yalova Carliston pepper seeds 85 and 94.43%, respectively. The sphericity of the pepper seeds ranged from 51 to 57%. Moreover, Yağlık Kapya has the highest volume and mass of 1000 seeds. The porosity of pepper seeds ranged from 44.94 to 49.61%, and terminal velocity, which increased with the weight, ranged between 2.87 and 4.66 m s^{-1}.

3. The initial moisture and mineral matter contents of the pepper seeds were found to be in the range from 7.03 to 7.21% and from 1.89 to 2.33%, respectively. The highest moisture content, weight, and the mineral matter content were found in Yağlık Kapya. It was observed that the rehydration capacities and germination rates of pepper seeds ranged between 1.85 and 2.25, 93.67 and 95%, respectively.

4. The static friction angle and coefficient of the pepper cultivar seeds were determined using aluminium, stainless steel, galvanized iron, rubber, glass, and plywood plates; the plywood plate was determined to have the highest angle and coefficient for all cultivars. Besides, it was shown that with its highest static friction angle and coefficient, Cin Sus Yediveren was the smallest cultivar in terms of weight and volume.

5. Results have revealed the importance of the differences among species as well as cultivars while designing and manufacturing machines. In addition, some of the seed parameters could be used in studies in which genetic resources are evaluated.

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