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Assessment of Some Physical Properties and Germination Characteristics of Ereğli and Kırıkhan Local Population Black Carrot Seeds

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HIGHLIGHTS

- It is necessary to determine the physical properties of black carrot seeds from local populations in Ereğli and Kırıkhan.
- The germination behaviour of the seeds needs to be determined, and their differences highlighted.
- Such information will provide insights that can guide future studies in black carrot farming and seed processing technology.

Abstract

Nowadays, food production and food security are an extremely important issue. Seed is of great importance for maintaining and securing crop production capacity. It is also necessary to protect gene resources and to apply new technologies. This study examined physical properties and germination parameters of calibrated black carrot seeds from the local populations S_1 (Ereğli) and S_2 (Kırıkhan). The length, width, thickness, geometric mean diameter, sphericity, projected area, volume, thousand grain weight, bulk density and terminal velocity values of the seeds of S_1 population at 3.96% moisture content were determined as 3.95 mm, 1.65 mm, 0.98 mm, 1.84 mm, 0.47, 5.18 mm^2, 2.01 mm^3, 2.51 g, 0.431 gcm^{-3}, and 1.80 ms^{-1}, respectively. Moreover, those values for S_2 population seeds were found to be 3.61 mm, 1.46 mm, 0.82 mm, 1.62 mm, 0.45, 4.55 mm^2, 1.37 mm^3, 2.21 g, 0.395 gcm^{-3}, and 1.75 ms^{-1} at 4.45% moisture level, respectively. Final germination seed (FGS), mean germination time (MGT), germination index (GI), germination rate index (GRI) and coefficient of velocity of germination (CVG) values of S_1 and S_2 variety seeds were 85% and 81%, 4.52 and 3.50 days, 548.5 and 574, 20.85 and 28.52 % day^{-1}, 22.20 and 28.79, respectively. The data obtained from this study will guide future studies on black carrot cultivation and seed processing technology.

Keywords: Black carrot seeds; Physical properties; Germination parameters; Color characteristics

1. Introduction

In contemporary times, feeding the world's population is among the most significant challenges. For this reason, it is necessary to develop a large number of varieties due to the decrease in agricultural land, changing consumer preferences and the wide range of consumption of people.

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Carrot is one of the vegetable varieties known for many years and produced in our country. Carrot (*Daucus carota* L.), a member of the genus Daucus, is a cultivated plant of the Apiaceae family (Simon and Goldman 2007). Additionally, the black carrot species belongs to Daucus carota ssp. sativus var. atrorubens Alef. Black carrot originates from Turkey, the Middle and Far East as well as it has been cultivated for at least 3 000 years (Montilla et al. 2011).

Carrot is a root vegetable that contains many bioactive compounds, for example, carotenoids, phenolic acids and anthocyanins. In addition, carrots are great sources of vitamins as well as minerals. Due to bioactive compounds, a carrot provides significant health benefits. It was demonstrated that carrots display powerful antioxidant and radical scavenging activities. Moreover, the consumption of carrots has been linked with a lower risk of diseases such as atherosclerosis, cataract, diabetes and cancer (Sharma et al. 2012).

Black carrots exhibit a purple hue due to their abundant anthocyanin content. These anthocyanins demonstrate considerable stability when exposed to light, heat, and variations in pH, rendering them ideal for use as natural colorants in food products.

Black carrot extracts are currently employed as natural colorants across various industries, including food, textiles, cosmetics, and pharmaceuticals, as a replacement for synthetic dyes. Additionally, these extracts are utilized in the coloring of fruit juices, jellies, confectioneries, jams, canned and frozen desserts, ice creams, soft drinks, and other fermented beverages (Barczak 2005; Ersus and Yurdagel 2007). Approximately 20% of the black carrot yield is dedicated to the turnip industry, while the remaining 80% is used for concentrate production. There is no specific data regarding the production area and amount of black carrot according to TurkStat. However, carrot production area and amount were stated 77 660 da and 522 410 t for Konya, 22 022 da and 70 710 t for Hatay provinces as well as those values were 136 627 da and 777 908 t for Turkey in 2023, respectively (TurkStat 2024).

Black carrots are also produced in Ereğli and Karapınar Districts of Konya and Kırıkhan District of Hatay Province. In these regions, hybrid black carrot seeds as well as local population black carrot seeds are used. Geographical indication registration was obtained for both Ereğli population black carrot (Anonymous 2017) and Kırıkhan local population black carrot (Anonymous 2022a).

Seed is of strategic importance for the agricultural sectors of countries. Local population seeds are used in regions where black carrot is produced. These seeds should be certified. These seeds should not only be used as an agricultural input. Additionally, their economic value should be enhanced by using technology.

In Ereğli and Kırıkhan Districts, planting is implemented with local population black carrot seeds. The color value of the Kırıkhan local variety of black carrot surpasses that of the Ereğli variety. Therefore, concentrate companies prefer the cultivation of the Kırıkhan local population black carrot in Konya's Ereğli and Karapınar districts for its superior color quality in concentrates. Besides, seed production for both populations is also carried out in the Konya region.

Carrot seeds are small and usually yellowish to dark gray in color and often appear slightly fuzzy. These fuzzy make up approximately 20-30% of the seed weight.

Research on carrot seed production in our country is limited; however, there are some significant studies. Kiracı (2013), established the gene pool of various purple carrot types grown and used in industry in Konya and its surroundings, facilitating the selection of lines in the pool.

Lökoğlu (2019), investigated the effect of root size and storage conditions on seed yield and quality in seed carrot roots in the first stage and the effect of planting spacing on seed yield and quality characteristics in seed carrot roots in the second stage in order to solve the problem of seed production in black carrots.

Several studies have examined the physical properties of various seed varieties. Notable research includes investigations on sage seeds (Bayram et al. 2016), balm seeds (Dumanoğlu and Çakmak 2017), onion seeds (Dumanoğlu and Çakmak 2019), lettuce seeds (Çekim and Özarslan 2020), anise seeds (Dumanoğlu et al. 2020) and basil seeds (Dumanoğlu and Mokhtarzadeh 2021). However, there is a notable lack of studies on the physical and germination characteristics of calibrated bare black carrot seeds from the Ereğli and Kırıkhan local population black carrot seeds.

2. Materials and Methods

The production of two local population of black carrot seeds used in the research was carried out under by local farmers in the Ereğli region in 2023. Calibrated black carrot seeds were initially passed through rectangular sieves ranging from 1.75 to 1.50 mm, and then classified according to their specific gravity (Fig. 1).

Bare seeds Ereğli (S_1)

Bare seeds Kırıkhan (S_2)

Figure 1. Local population black carrot seeds used in the trials

Three groups of 50 seeds each were consisted of the Ereğli and Kırıkhan seeds separately and 50 seeds were randomly selected from both seed varieties. The dimensional properties and projected area of the bare black carrot’s seeds were measured using the "Image Tool version 3.0" image processing software. Using the length and width values obtained from the seeds, geometric and shape characteristics were determined (Table 1).

Table 1. Classification of seeds according to their geometric and shape characteristics (Yağcıoğlu, 2015)

Classes of geometric characteristic	Seed width/Seed length (W/L)
Long	< 0.6
Medium	0.6-.07
Short	> 0.7
Classes of shape characteristics	**Length(L), width(W), thickness (T) (mm)**
Round	L ≈ W ≈ T
Oval	L/3 < W ≈ T
Long	T< W < L/3

The geometric mean diameter, sphericity, and volume of the bare seeds were calculated using specific equations (Mohsenin, 1970).

Table 2. Geometric mean diameter, sphericity and volume symbols and formulas

Parameters	Units	Symbols	Equations
Geometric mean diameter	mm	Dg	$(L.W.T)^{1/3}$
Sphericity	-	∅	$\frac{D_g}{L}$
Volume	mm^3	V	$\frac{\pi B^2 L^2}{6.(2L-B)}$
			$B=(WT)^{0.5}$

*L: Length of seeds, *W: Width of seeds, *T: Thickness of seeds

In three replicates, the mass of one thousand randomly selected seeds was determined by counting them using a Contador brand seed counting device and measuring their weight on a precision scale.

Bulk density was evaluated using a weight per hectoliter tester, which was calibrated to measure in kilograms per hectoliter (Deshpande et al. 1993). Seeds were extracted using a strike-off stick, and no compaction was applied during testing.

The color values of the black carrot seeds were measured using a Minolta Chroma Meter model CR 400 (Konica Minolta, Inc., Osaka, Japan) color measurement device. In the measurements, the L*, a*, and b* scales, as defined by the International Commission on Illumination, were used (Rizzo et al. 2014). The measurements were taken on the exterior (skin) part of the seeds In the CIE L*, a*, b* color system, the L* value represents lightness, ranging from 0 (black) to 100 (white). The a* value signifies the red-green axis, with positive values indicating redness and negative values indicating greenness. The b* value corresponds to the yellow-blue axis, with positive values indicating yellowness and negative values indicating blueness (Jha et al., 2006).

The coefficient of static friction of black carrot seeds was determined by measuring their interaction with sheet iron, plastic, and galvanized sheet iron surfaces. In this setup, one end of the friction surface was fixed to an endless screw. The black carrot seeds were positioned on the surface, and the screw was gradually lifted. When the seeds began to slide, the vertical and horizontal height values were recorded. The coefficient of static friction was subsequently determined by calculating the tangent of the angle at which the sliding initiated (Baryeh 2001).

The terminal velocities of black carrot seeds were determined using an air column. During each test, a seed was released into the air stream from the top of the column, where upward-blown, air was used to suspend it. The velocity of the air at the point of suspension was measured with an electronic anemometer, accurate to 0.1 m s^{-1} (Hauhouot-O'Hara et al. 2000; Joshi et al. 1993).

A Nüve FN055 brand owen was used to measure the moisture content of the black carrot samples. The samples were dried at 105°C until they reached a constant weight.

The germination tests of black carrot seeds were carried out in a climate chamber, adhering to ISTA 2023 norms (Anonymous 2023). A hundred seeds from two different black carrot populations were placed in petri dishes with four replicates each, and daily counts were conducted.

Some concepts related to germination characteristics of black carrot seeds were given in list in Table 3. These parameters pertain to the number of germinating seeds and the initial development of seedlings.

Table 3. Basic concepts of germination characteristics

Parameters	Units	Symbols	Equations	References
Final germination seed	%	FGS	100* (Number of germination seeds / Total number of seeds)	(Scott et al., 1984)
Mean germination time*	Day	MGT	$\frac{\Sigma N_i . T_i}{\Sigma N_i}$	(Orchard, 1977)
Germination index**	-	GI	$14xN_1+13.N_2+\ldots..+1.N_{14}$	(Benech Arnold et al., 1991; Kader, 2005)
Germination rate index***	(% day^{-1})	GRI	$\frac{G_1}{1}+\frac{G_2}{2}+\frac{G_3}{3}+\ldots.+\frac{G_x}{14}$	(Al-Ansari and Ksiksi, 2016)
Coefficient of velocity of germination	-	CVG	$100 \cdot \frac{\sum N_i}{\Sigma N_i \cdot T_i}$	(Jones and Sanders, 1987)

*N_i is the number of germinated seeds for each day, T_i is number of days counted from the beginning of germination
**N_1, N_2 ...N_{14} is the number of germinated seeds on the first, second and subsequent days until 14th day and the multipliers (e.g. 14, 13, 12 ...etc.) weights are given to the days of the germination.
***G_1 is the germination percentage on day 1, G_2 is the germination percentage at day 2 and etc.

Variance analyzes were performed on the germination parameters of black carrot seeds using the MINITAB 16 program.

3. Results and discussion

3.1. Physical properties of black carrot seeds

Some physical properties of classified bare black carrot seeds from S_1 (Ereğli) and S_2 (Kırıkhan) local populations are detailed in Table 4. For S_1 seeds with a moisture content of 3.96%, the values are: length 3.95 mm, width 1.65 mm, thickness 0.98 mm, geometric mean diameter 1.84 mm, sphericity 0.47, and projected area 5.18 mm². For S_2 seeds with a moisture content of 4.45%, the values are: length 3.61 mm, width 1.46 mm, thickness 0.82 mm, geometric mean diameter 1.62 mm, sphericity 0.45, and projected area 4.55 mm². In general, all measured dimensional properties of S_1 seeds were found to be higher compared to S_2 seeds. It has been reported that in the study conducted on onion seeds, the average length, width, and projection area of the seeds in the control group were determined to be 1.52 mm, 1.06 mm, and 1.26 mm², respectively (Dumanoğlu and Çakmak 2019). According to research findings, (Tang et al. 2015) reported the length, width, and thickness values for tomato seeds as 3.33 mm, 2.36 mm, and 0.63 mm, respectively. For cabbage seeds with 8.24% moisture content, the length, width, and sphericity values were reported as 2.03 mm, 1.79 mm, and 0.85, respectively (Jadhav et al. 2017).

In terms of shape characteristics, the width/length (W/L) ratio was determined to be 0.43±0.011 for seeds from the S_1 local population and 0.41±0.011 for seeds from the S_2 population. Both populations were classified as having long seeds. Regarding shape characteristics, the L/3 values for seeds from the S_1 and S_2 populations were found to be 1.32 and 1.20, respectively. These values were lower than 1.65 and 1.46 (W), indicating that the seeds fell into the oval category.

Table 4. Dimensional properties of bare seeds S_1 and S_2 population

Properties	S_1 seeds	S_2 seeds
Moisture (m.c.d.b.) (%)	%3.96	%4.45
Length (mm)	3.95±0.067	3.61±0.071
Width (mm)	1.65±0.027	1.46±0.029
Thickness (mm)	0.98±0.031	0.82±0.028
Geometric mean diameter, (mm)	1.84±0.025	1.62±0.026
Sphericity (Ø)	0.47±0.006	0.45±0.008
Projected area (mm²)	5.18±0.102	4.55±0.119

To compare the length, width, thickness, geometric mean diameter, and sphericity values between the two black carrot seed populations, relationships were established. For the S_1 local population seeds, the relationships are:

$$L = 2.394 \times W = 4.031 \times T = 2.147 \times GMD = 8.404 \times Ø$$

For the S_2 population, the relationships are:

$$L = 2.473 \times W = 4.402 \times T = 2.228 \times GMD = 8.022 \times Ø$$

The coefficients of correlation for these relationships show provided in Table 5. In the S_1 population, the relationships between L/T, L/GMD, and L/Ø were statistically significant, while in the S_2 population, the relationships between L/GMD and L/Ø were statistically significant

Table 5. The correlation coefficients of black carrot seeds of S_1 and S_2 population

Variety	Particulars	Ratio	Degrees of freedom	Correlation coefficient
S_1 seeds	L/W	2.394	48	-0.1262
	L/T	4.031	48	0.3755**
	L/GMD	2.147	48	0.6603**
	L/S	8.404	48	-0.6485**
S_2 seeds	L/W	2.473	48	0.0896
	L/T	4.402	48	0.0265
	L/GMD	2.228	48	0.4628**
	L/S	8.022	48	-0.6631**

**p>0.01

Similar results were obtained in the research conducted with okra seeds, and high correlation coefficients were found between L/T, L/GMD, and L/Ø values (Çalışır et al. 2005).

Some physical properties of black carrot seeds are detailed in Table 6. For S_1 population seeds, the volume, thousand grain weight, bulk density, and terminal velocity values were found to be 2.01 mm^3, 2.51 g, 0.431 gcm^{-3}, and 1.80 m s^{-1}, respectively. In comparison, S_2 population seeds had lower values of 1.37 mm^3, 2.21 g, 0.395 g cm^{-3}, and 1.75 m s^{-1}, respectively. The static coefficient of friction values for S_1 seeds on galvanized sheet iron, steel sheet, and plastic surfaces were 0.620, 0.664, and 0.706, respectively, while for S_2 seeds, these values were higher at 0.674, 0.743, and 0.789, respectively. The higher static coefficient of friction for S_2 seeds is attributed to their lower sphericity and fuzzy structure. According to the results of studies conducted with vegetable seeds, similar results were obtained in terms of physical properties. In the study conducted with tomato seeds, the thousand seeds weight was found to be 2.8 g and the critical velocity was 3.78 m s^{-1} (Tang et al. 2015). Additionally, it was reported that at a moisture level of 9.94%, the thousand-seed weight, critical velocity, and bulk density values of tomato seeds were 2.63 g, 2.67 m s^{-1}, and 0.3 g cm^{-3}, respectively (Jadhav et al. 2017).

Table 6. Physical properties of black carrot seeds of S_1 and S_2 population at 3.96 and 4.45% (m.c.d.b)

Properties	S_1 seeds	S_2 seeds
Volume (mm^3)	2.01±0.090	1.37±0.077
Thousands seeds weight of carrot (g)	2.51±0.234	2.21±0.034
Bulk density (g cm^{-3})	0.431±0.0136	0.395±0.007
Terminal velocity (m s^{-1})	1.80±0.019	1.75±0.019
Static coefficient of friction		
Galvanized sheet iron	0.623±0.020	0.674±0.024
Steel sheet,	0.664±0.018	0.743±0.022
Plastic	0.692±0.023	0.789±0.028
Color characteristics		
L	46.18±0.961	51.41±0.656
a*	4.70±0.068	4.59±0.249
b*	16.23±0.341	18.23±0.683

When considering parameters in the commonly used CIELAB system, the L, a, and b values for seeds from the S_1 and S_2 populations were found to be 46.18 and 51.41, 4.70 and 4.59, and 16.23 and 18.23, respectively. It can be observed that while the values are close, the S_2 population has a slightly brighter (higher L value) and more yellowish (higher b value) color. These minor differences, despite the overall similarity in color between the two populations, can provide distinguishability under specific lighting and color conditions.

3.2. Germination properties of black carrot seeds

Seed germination is an estimate of the viability of a population of seeds. The higher the FGP value, the greater the germination of a seed population. The bare black carrot seeds from the S_1 and S_2 populations have been observed to complete germination in 10 and 9 days, respectively. This indicates that the germination period of seeds from the S_1 population is one day longer than that of the seeds from the S_2 population (Fig. 2). The final germination percentage of bare black carrot seeds obtained from S_1 and S_2 populations was found to be respectively. For certification requirements, it is desired that the germination percentages of standard carrot seeds do not fall below 75% (Anonymous 2022b).

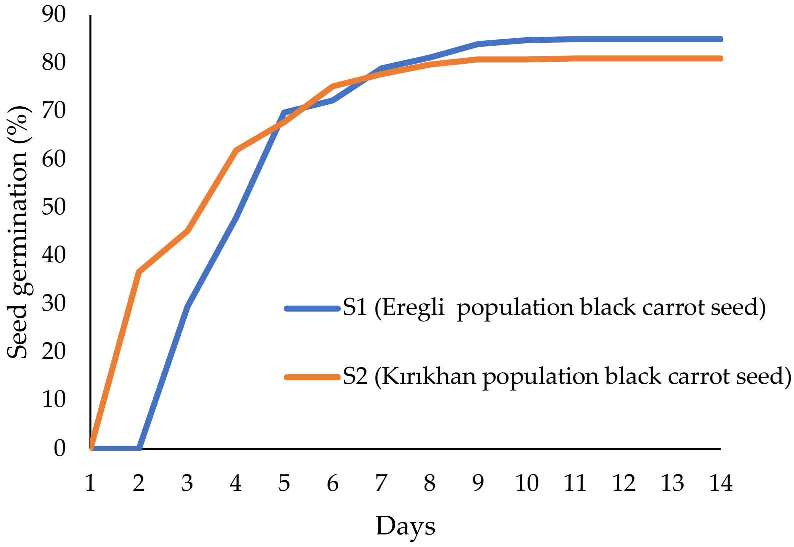

Figure 2. Cumulative seed germination of uncoated S_1 and S_2 black carrot seeds

Therefore, the black carrot seeds obtained from the two local populations fall into the standard seed group. As a result of the variance analysis applied to the germination values, no statistical difference was found among the black carrot seeds (Table 7).

Table 7. Germination parameters of black carrot seeds

Seeds	FGS (%)	MGT (day)	GI -	GRI (% day^{-1})	CVG -
S_1 (Ereğli)	84.75	4.52$_a$	548.5	20.85$_a$	22.20$_a$
S_2 (Kırıkhan)	80.75	3.50$_b$	574.0	28.52$_b$	28.79$_b$
Standard error of the mean (SEM)	0.0171	0.1606	20.33	0.8540	1.035
P-value	0.066	0.004	0.409	0.001	0.004

MGT is an accurate measure of the time taken for a lot to germinate but does not correlate this well with the time spread or uniformity of germination. The lower the MGT, the faster a population of seeds has germinated (Orchard, 1977). The Mean Germination Time (MGT) values for seeds from the S_2 population were found to be an average of 3.50 days, while the MGT values for seeds from the S_1 population were found to be an average of 4.52 days. This difference in MGT values was found to be statistically significant (Table 7). In a study conducted under laboratory conditions with seeds from different basil populations, the average germination time values were reported to range between 2.17 and 2.25 days (Dumanoğlu and Mokhtarzadeh 2021). Additionally, the average germination time of anise seeds from the Turkish line was reported to be 5.25 days (Dumanoğlu et al., 2020).

In Germination Index (GI), seeds that germinate on the first day are given maximum weight, while seeds that germinate later are given progressively less weight. Therefore, the GI emphasizes both the germination percentage and the speed of germination. A higher GI value indicates a higher germination percentage and rate (Benech Arnold et al. 1991). The Germination Index (GI) values for black carrot seeds from the S_2 and S_1 populations were found to be 574 and 548.5, respectively. Although the GI was higher in the S_2 variety, this difference was found to be statistically insignificant.

The GRI reflects the percentage of germination on each day of the germination period. Higher GRI values indicate higher and faster germination. Germination Rate Index (GRI) was determined to be 20.85 %.day^{-1} for seeds from the S_1 population and 28.52 %. day^{-1} for seeds from the S_2 population. This difference was found to be statistically significant.

The Coefficient of Velocity of Germination (CVG) gives an indication of the rapidity of germination. It increases when the number of germinated seeds increases, and the time required for germination decreases.

Theoretically, the highest possible CVG is 100, which would occur if all seeds germinated on the first day (Jones and Sanders 1987). The CVG value for black carrot seeds from the S_2 population was 28.96, while the CVG value for seeds from the S_1 population was lower at 22.20. This difference was found to be statistically significant.

4. Conclusions

Recognizing the physical properties of black carrot seeds is essential for mechanization applications such as storage, cleaning, grading, coating, and sowing with pneumatic precision vegetable planters. Both populations of black carrot seeds were found to have a long and oval shape. The seeds from the S_1 population have greater values in terms of length, width, thickness, geometric mean diameter, and projected area compared to the S_2 seeds. Specifically, these values for S_1 seeds are 3.95 mm, 1.65 mm, 0.98 mm, 1.84 mm, and 5.18 mm², respectively, whereas for S_2 seeds they are 3.61 mm, 1.46 mm, 0.82 mm, 1.62 mm, and 4.55 mm², respectively. The sphericity, which indicates how close the shape of the seed is to a sphere, was found to be slightly higher in S_1 seeds (0.47) compared to S_2 seeds (0.45). S_2 seeds have lower values for volume (1.37 mm³), thousand grain weight (2.21 g), bulk density (0.39 g cm^{-3}), and terminal velocity (1.73 m s^{-1}) compared to S_1 seeds. However, the static coefficient of friction values for S_2 seeds are higher on galvanized sheet iron (0.674), steel sheet (0.743), and plastic surfaces (0.789). The color values (L, a, and b) for seeds from the S_1 and S_2 populations were found to be 46.18 and 51.41, 4.70 and 4.59, and 16.23 and 18.23, respectively. Although the values are close, the S_2 population seeds are slightly brighter (higher L value) and more yellowish (higher b value) in color. The germination rate values of black carrot seeds were found to be 84.75% for the S_1 population and 80.75% for the S_2 population. The Mean Germination Time (MGT) values were 4.52 days and 3.50 days, respectively. The S_1 population shows a higher germination rate, while the S_2 population germinated in a shorter time. The GI value was found to be 574 for the S_2 variety and 548.5 for the S_1 population. In other words, we can say that the S_2 population germinates more quickly. The GRI value was 28.52 for the S_2 variety and 20.85 for the S_1 population, indicating that the germination percentage was higher each day during the germination period for the S_2 population. The Coefficient of Velocity of Germination (CVG) was 28.79 for the S_2 variety and 22.20 for the S_1 population, suggesting that the time required for germination is shorter for the S_2 variety. The data obtained from this research are expected to be helpful for future studies.

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