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Effect of Foliar Application of Boron on Yield and Yield Components of Linseed Cultivars (*Linum usitatissimum* L.)

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Abstract: Boron is a crucial micronutrient for the growth and development of plants. Foliar application of boron positively impacts the growth, yield, and yield components of oilseed crops. The objective of this study was to determine the effect of boron (B) on some yield and quality traits of linseed cultivars. The field experiments of this study were carried out in spring season of 2022 and 2023 under ecological conditions of Tekirdag. The experiment was carried out as a split plot design based on RCBD with three replications, in which cultivars constituted the main plot with three varieties (Karakız, Sarı Dane and Beyaz Gelin), and boron constituted the sub-plot with four doses (0, 100, 200 and 300 mg L^{-1}) in both years. Boron doses were applied by foliar spraying at 45 DAS. In the study plant height, branch number, number of capsules per plants, number of seeds per capsule, 1000 seed weight, seed yield, oil content and oil yield were investigated. Analysis of variance showed that boron application significantly affected all the examined traits except for 1000 seed weight and oil content. The results showed that the highest seed yield was obtained from 200 and 300 mg L^{-1} boron application (91.45 and 93.85 kg da^{-1}, respectively). However, the differences in oil content were not statistically significant in terms of cultivar and boron application. In conclusion, foliar application of appropriate doses of boron contributes to increase the yield of linseed, especially in medium and low input farming systems.

Key words: Boron, Linseed, Micronutrients, Quality, Yield

Yapraktan Bor Uygulamasının Keten (*Linum usitatissimum* L.) Çeşitlerinin Verim ve Verim Unsurları Üzerine Etkisi

Öz: Bor, bitki büyümesi ve gelişimi için önemli mikro besin elementlerinden birisidir. Borun yapraktan uygulanması yağlı tohumlarda tohum verimini ve verim unsurlarını olumlu yönde etkilemektedir. Bu çalışmada, farklı dozlarda bor uygulamasının keten çeşitlerinin verim ve bazı kalite özelliklerine etkilerinin belirlenmesi amaçlanmıştır. Çalışma, Tekirdağ ekolojik koşullarında 2022 ve 2023 yıllarında yazlık olarak iki yıl süreyle yürütülmüştür. Deneme Tesadüf Bloklarında Bölünmüş Parseller Deneme Desenine göre çeşitler ana parselde (Karakız, Sarı Dane ve Beyaz Gelin), bor dozları ise alt parselde (0, 100, 200 ve 300 mg L^{-1}) olacak şekilde 3 tekrarlamalı olarak kurulmuştur. Bor dozları bitkilere ekimden 45 gün sonra yapraktan püskürtme yoluyla uygulanmıştır. Çalışmada bitki boyu, dal sayısı, bitki başına kapsül sayısı, kapsüldeki tohum sayısı, 1000 tane ağırlığı, tohum verimi, yağ oranı ve yağ verimi gibi özellikler incelenmiştir. Varyans analizi sonucuna göre bor uygulaması 1000 tane ağırlığı ve yağ oranı hariç incelenen tüm özellikleri önemli ölçüde etkilemiştir. Araştırma sonuçlarına göre en yüksek tohum verimi 200 ve 300 mg L^{-1} bor uygulamasından elde edilmiştir (sırasıyla 91,45 ve 93,85 kg da^{-1}). Ancak yağ oranı arasındaki farklılıklar çeşit ve bor uygulaması bakımından istatistiki olarak önemli bulunmamıştır. Sonuç olarak uygun dozlarda borun yapraktan uygulanması, özellikle orta ve düşük girdili tarım sistemlerinde ketenin tohum veriminin artmasına katkıda bulunabilir.

Anahtar kelimeler: Bor, Kalite, Keten, Mikro Besin, Verim

1. Introduction

Although there are many oilseed crops in the world, the plants that are widely used in the vegetable oil industry today are soybean, rapeseed, cottonseed, peanut, sunflower, sesame, safflower, poppy, linseed, hemp, castor oil, jojoba, corn, olive, palm and coconut. All of these oilseed crops except jojoba, palm and coconut can be cultivated in Turkiye due to the ecological conditions they require (Vollmann & Rajcan, 2010; Onat et al., 2017). Linseed (*Linum usitatissimum* L.) is the only economically important crop species in the *Linaceae* family, which comprises 13 genera and approximately 300 species. The term *usitatissimum*, meaning "most useful," is used because of the linseed's long-standing significance as an agricultural crop (Chand & Fahim, 2008; Koçak & Bayraktar, 2011). It is grown either for its fiber (fiber flax) or for its oil (oilseed flax) (Hall et al., 2016). Tall, heavily branched varieties with strong fibers are cultivated for fiber production, while shorter, fewer branching varieties are grown for oil production (Yıldırım & Arslan, 2013).

Linseed contains 35-45% and oil 20-25% protein (Gill, 1987). Its oil is a rich source of omega-3 (ω-3, alpha-linolenic acid) which is important in human nutrition. Omega-3 contains approximately 50-55% of fatty acids (Bloedon & Szapary, 2004; Bayrak et al., 2010; Culpan & Gürsoy, 2023). Studies and researches continue for the development and popularization of linseed cultivation. Among these studies, micronutrient applications play an important role in increasing seed yield and quality. Boron is a crucial micronutrient for the growth and development of plants (Warington, 1923; Güneş et al., 2017). It participates in the process of pollination, fertilization and plant fruit setting. In addition, boron enhances the formation of adenosine triphosphate (ATP) and serves as a compound that accelerates the movement of sugars into the active areas during growth throughout the reproduction stages of the plant (Bolanos et al., 1996; Al-Juheishy, 2020).

It is known that when the boron level in the soil is 1 ppm, boron is sufficient, but when it exceeds 5 ppm, it has a toxic effect on the soil (Sahin, 2014). Many researchers have reported that in boron-deficient soils, boron application through soil and foliar spraying positively affects seed yield and yield components of plants (Katar et al., 2014; Rawashdeh & Sala, 2014; Mekki, 2015; Kurşun et al, 2016; Megha et al., 2023). These positive effects are especially evident in soils deficient in boron (< 1 ppm).

Boron content of 409 soil samples representing the sunflower cultivation areas of Thrace region showed a distribution between 0.14 mg kg^{-1} and 2.42 mg kg^{-1}. In 304 of the samples, boron content was 1 mg kg^{-1} and below. In 16% of the sunflower cultivation areas in Thrace region, boron level is insufficient and below 0.5 mg kg^{-1}, and boron fertilization in these areas in the amount and form recommended according to the results of soil analysis is necessary for both yield increase and crop quality (Kurşun et al., 2016). In general, 100-200 g da^{-1} boron is recommended for plants with low boron requirements such as cereals, while this rate can increase to 400 g for plants with high boron requirements such as sugar beet, rapeseed and sunflower. In foliar boron fertilization, the generally accepted rate is 250-300 mg L^{-1} (Güneş et al., 2017).

The aim of this study was to determine the effects of boron (B) on some yield and quality characteristics of linseed cultivars under Tekirdağ ecological conditions.

2. Materials and Methods

The research was conducted at the Area of Research and Experiment, Field Crops Department, Faculty of Agriculture, Tekirdag Namik Kemal University, during 2022 and 2023. The climatic and soil characteristics of the experimental area are given in Table 1 and Table 2. The climate characteristics of the research field are sufficient and suitable for linseed (Table 1), but when the soil properties are examined, it is seen that it is insufficient in terms of boron. (Table 2).

In the study, Karakız, Sarı Dane and Beyaz Gelin cultivars obtained from the Trakya Agricultural Research Institute (Edirne) were used as material. These cultivars are oilseed flax types, with seed yield values ranging from 80 to 100 kg da^{-1} and oil content between 30% and 35% (Anonymous, 2020).

The experiment was arranged in a split plot with randomized complete block design in three replications, in which cultivars constituted the main plot with three varieties (Karakız, Sarı Dane and Beyaz Gelin), and boron constituted the sub-plot with four doses (0, 100, 200 and 300 mg L^{-1}) in both years. Boron is obtained from water-soluble 8% w/w Boron Ethanolamine (Boron-8, Gubretas). Boron doses were applied by foliar spraying 45 days after sowing (at 45 DAS) (Alam et al., 2020; Singh et al., 2020).

Table 1. The climatic conditions of the experimental area and long-term averages
Çizelge 1. Deneme alanının iklim verileri ve uzun yıllar ortalamaları

Month	Mean temperature (°C)			Total rainfall (mm)			Mean humidity (%)		
	2022	2023	LTA	2022	2023	LTA	2022	2023	LTA
March	5.2	9.3	7.7	9.5	48.4	49.8	71.5	81.2	80.6
April	12.7	12.0	11.9	70.6	93.5	42.8	74.3	82.3	78.2
May	16.9	15.8	16.7	15.7	27.6	39.1	75.2	80.3	77.1
June	22.5	21.2	21.3	32.5	16.3	39.2	74.5	77.5	73.9
July	24.3	25.7	23.9	1.5	15.2	26.5	68.8	71.2	70.4
Mean/Total	16.3	16.8	16.3	129.8	201.0	197.4	72.8	78.5	76.0

* Tekirdag Meteorological Station Data, LTA: long-term averages (1972-2022)

Table 2. The soil characteristics of the experimental area
Çizelge 2. *Deneme alanının toprak özellikleri*

Variable	Unit	2022	2023	Assessment
pH	-	7.17	7.22	medium
Salt	%	0.02	0.02	none
Organic matter	%	1.06	1.15	low
Phosphorus	kg da^{-1}	6.4	8.7	low
Potassium	kg da^{-1}	96.6	102.5	high
Boron (B)	ppm	0.49	0.55	low
Texture	-	Clay	Clay	-
Depth	cm	0-20	0-20	-

Nitrogen and phosphorous were applied at the rate of 80 kg ha^{-1} N (urea) and 60 kg ha^{-1} P (Diammonium phosphate), respectively. All the phosphorus and half of the nitrogen were applied before sowing the seeds, while the remaining nitrogen was applied during the stem elongation stage (about one month after sowing). Ten plants per plot were randomly selected to determine yield and yield components. In the study plant height (cm), branch number (pcs), number of capsules per plants (pcs), number of seeds per capsule (pcs), 1000 seed weight (g), seed yield (kg da^{-1}), oil content (%) and oil yield (kg da^{-1}) were investigated. The linseed plants were harvested by hand on August 2, 2022, and July 17, 2023. For the seeds from each plot, the oil content (as a percentage) was measured using a Nuclear Magnetic Resonance (NMR) device. The oil yield was calculated by multiplying the seed yield by the oil content of the seeds (Abou Chehade et al., 2022).

The analysis of variance was carried out over two years for the values of all traits. The data obtained were analyzed according to randomized complete block design. The means were compared by using the Least Significant Difference (LSD) test at the 0.05 and 0.01 levels as described by Steel and Torrie (1980) with MSTAT-C statistical software (MSTAT, 1989).

3. Results and Discussion

The variance analysis results of this study, which was conducted to determine the effects of boron applications on the seed yield, yield components, oil content, and oil yield of linseed under field condition, are given in Table 3.

Cultivars had a significant effect on 1000 seed weight at the 1% level, and on branch number, seed yield, and oil yield at the 5% level. In terms of applied doses, all the examined traits, except for 1000 seed weight and oil content, showed statistically significant differences at the 1% level. Cultivar × Boron doses interactions had significant effects ($p<0.05$) on branch number and 1000 seed weight (Table 3).

In terms of plant height, the lowest plant height was observed in the control plots where boron was not applied (38.08 cm). In the cultivar × boron interaction, plant height values varied between 36.07-45.12 cm, but this difference was not found statistically significant ($p>0.05$). Zahoor et al. (2011) reported that plant height significantly increased when boron levels increased in sunflower. Alam et al. (2020) showed that treating linseed with a foliar application of $ZnSO_4$ at 0.5% combined with Borax at 0.3% at 45 days after sowing resulted in significantly higher plant heights (53.75 cm and 55.14 cm) compared to the control (42.18 cm and 43.53 cm). Beyzi et al. (2019) found that the highest plant height (58.18 cm) in fenugreek was obtained from 800 mg L^{-1} boron application and reported that plant height increased with boron applications compared to control applications. Our results confirm the findings of earlier researchers. In addition, plant height, which is much more important in fiber flax varieties and desired to be longer, is a character that directly affects seed yield to a certain extent in oilseed flax varieties, provided that side branches are formed (Culbertson, 1954; Çöl Keskin et al., 2020).

In boron application, the branch number increased significantly with increasing boron doses and the highest branch number was obtained from 300 mg L^{-1} boron application with 8.65 pcs (Table 4). In the cultivar × boron interaction, the highest branch number was obtained from Sarı Dane cultivar with 300 mg L^{-1} boron application and Beyaz Gelin cultivar with 200 and 300 mg L^{-1} (8.92, 8.39 and 8.78 pcs, respectively).

Table 3. Analysis of variance for some agronomical and technological traits of linseed
Çizelge 3. *Ketenin bazı agronomik ve teknolojik özelliklerine ilişkin varyans analizi*

SV	DF	Plant height	Branch number	Number of capsules per plants	Number of seeds per capsule	1000 seed weight	Seed yield	Oil content	Oil yield
Cultivar (C)	2	0.7934^{ns}	7.7444*	1.4571^{ns}	2.7942^{ns}	28.9777**	7.3128*	4.2125^{ns}	7.8346*
Error$_1$	4								
Boron (B)	3	11.8957**	28.7479**	15.7711**	8.5118**	1.8097^{ns}	18.1866**	0.6244^{ns}	16.1485**
C x B	6	0.4093^{ns}	2.8136*	0.4371^{ns}	0.4340^{ns}	2.8908*	0.6726^{ns}	0.2710^{ns}	0.5273^{ns}
Error	18								
CV (%)		5.46	4.09	17.32	5.71	2.26	5.56	1.15	6.05

SV: source of variation, DF: degree of freedom, ns: not significant, *, ** significant at 0.05 and 0.01 probability levels, respectively

A high number of branches in linseed is a desirable character as it contributes to the increase in the number of capsules per plant, especially in oilseed flax varieties (Endes, 2010). Karaaslan and Tonçer (2001) determined the number of branches per plant as 4.3-6.6 as a result of a study conducted in Diyarbakır ecological conditions using 11 different linseed varieties as winter crops. Kurt et al. (2015) reported that the branch number per plant of 30 linseed lines varied between 4.4-7.4 pcs in Samsun ecological conditions. Al-Doori (2021) determined the branch number in linseed as 9.06-11.54 pcs and reported that the branch number increased with increasing boron levels. Our results fell within the ranges reported by these researchers.

The number of capsules per plants in linseed is low in frequent sowing and high in infrequent sowing (Uzun, 1992; Saeidi, 2002). In boron application, the number of capsules per plants increased significantly with increasing boron doses and the lowest number of capsules per plants was observed in the control plots where boron was not applied (11.20 pcs). In the cultivar × boron interaction, number of capsules per plants values varied between 10.00-23.40 pcs, but this difference was not found statistically significant ($p>0.05$). Studies have shown that number of capsules per plants in linseed varies between 16.4 and 22.2 pcs (Gür, 1998), 14.1 and 29.0 pcs (Akçalıcan et al., 2003), 25.6 and 47.1 pcs (Kurt et al., 2015), 14.07 and 19.07 pcs (Arslan & Culpan, 2021). Al-Doori (2021) reported that increasing foliar application of boron significantly enhanced number of capsules per plant. Beyzi et al. (2019) found that greatest number of pods per plant (8.63 pods plant^{-1}) in fenugreek was obtained from 800 mg L^{-1} boron application and reported that plant height increased with boron applications compared to control applications. In previous studies, it was reported that the number of pods per plant increased with boron applications in chickpea (Ceyhan et al., 2007), common bean (Harmankaya et al. 2008), peanut (El-Kader & Mona, 2013) and sesame (Khuong et al., 2022) plants compared to control treatments. The present findings were similar with the results of previous researchers.

The number of seeds per capsule was significantly affected by boron application and highest number of seeds per capsule was obtained from 300 mg L^{-1} boron application (8.49 pcs). Kurt et al. (2015) and Yıldırım & Arslan (2013) reported that the number of seeds per capsule in linseed varied between 6.40-8.10 and 7.98-9.03 pcs, respectively. Alam et al. (2020) emphasize that the significantly higher number of seeds per capsule (6.00 and 8.57 pcs) was observed with the foliar application of $ZnSO_4$ at 0.5% and Borax at 0.3% at 45 days after sowing (DAS), compared to the control.

Table 4. Some agronomical and technological traits of linseed and LSD groups
Çizelge 4. *Ketenin bazı agronomik ve teknolojik özelliklerine ait ortalama değerler ve önemlilik grupları (EKÖF)*

		Plant height (cm)	Branch number (pcs)	Number of capsules per plants (pcs)	Number of seeds per capsule (pcs)	1000 seed weight (g)	Seed yield (kg da^{-1})	Oil content (%)	Oil yield (kg da^{-1})
Cultivar (C)									
Karakız		43.23	7.68 **b**	15.32	7.78	7.21 **a**	105.19 **a**	35.96	37.80 **a**
Sarı Dane		41.75	7.91 **ab**	19.32	7.38	6.57 **b**	71.72 **ab**	36.02	25.83 **ab**
Beyaz Gelin		40.12	8.35 **a**	16.38	8.58	6.18 **b**	84.36 **b**	35.46	29.90 **b**
Boron Doses (B)									
0		38.08 **b**	7.47 **c**	11.20 **b**	7.42 **b**	6.57	78.75 **b**	35.66	28.09 **b**
100		41.47 **a**	7.51 **c**	19.07 **a**	7.93 **ab**	6.63	84.30 **b**	35.84	30.19 **b**
200		43.35 **a**	8.29 **b**	18.32 **a**	7.82 **b**	6.69	91.45 **a**	35.84	32.78 **a**
300		43.88 **a**	8.65 **a**	19.44 **a**	8.49 **a**	6.72	93.85 **a**	35.91	33.65 **a**
C x B									
Karakız	0	39.72	6.94 **d**	10.00	7.13	7.08 **b**	95.50	35.89	34.31
	100	43.53	7.30 **d**	17.60	7.80	7.21 **ab**	100.76	35.95	36.17
	200	45.12	8.23 **bc**	16.66	7.73	7.43 **a**	111.42	36.10	40.18
	300	44.54	8.25 **bc**	17.00	8.47	7.12 **b**	113.09	35.90	40.56
Sarı Dane	0	38.46	7.29 **d**	12.20	6.80	6.56 **cd**	65.99	35.72	23.57
	100	41.45	7.19 **d**	20.73	7.33	6.59 **cd**	70.67	36.09	25.48
	200	42.30	8.24 **bc**	20.97	7.40	6.40 **de**	73.94	36.04	26.65
	300	44.76	8.92 **a**	23.40	8.00	6.75 **c**	76.26	36.22	27.62
Beyaz Gelin	0	36.07	8.19 **c**	11.40	8.33	6.07 **f**	74.76	35.36	26.40
	100	39.42	8.05 **c**	18.87	8.67	6.10 **f**	81.47	35.47	28.91
	200	42.62	8.39 **abc**	17.33	8.33	6.25 **ef**	89.00	35.40	31.52
	300	42.35	8.78 **ab**	17.93	9.00	6.29 **ef**	92.22	35.62	32.76
Mean		**41.69**	**7.98**	**17.01**	**7.91**	**6.65**	**87.09**	**35.81**	**31.17**

Means followed by the same letter within columns are not significantly different at the level of $p < 0.05$

Cultivars had significant effects on 1000 seed weight ($p<0.01$) and its highest was obtained from Karakız cultivar (7.21 g). In the cultivar × boron interaction, the highest 1000 seed weight was obtained from Karakız cultivar with 100 and 200 mg L^{-1} boron application (7.21 and 7.43 g, respectively). In oilseeds, 1000 seed weight refers to the fullness and size of the seeds. Therefore, it is very important in terms of both seed yield and oil content (Vollman & Rajcan, 2009; Tunçtürk & Tunçtürk, 2021). Studies have shown that 1000 seed weight in linseed varies between 7.10-7.60 g (Rokade et al., 2015), 7.87-9.30 g (Maurya el al. 2017) and 5.04-5.77 g (Arslan & Culpan, 2021). Alam et al. (2020) found that the significantly higher 1000 seed weight (7.59 g and 7.64 g) was observed with the foliar application of $ZnSO_4$ at 0.5% and Borax at 0.3% at 45 days after sowing, compared to the control. Saeed et al. (2015) emphasized that foliar boron application increased 1000-achene weight (42.74 g) in sunflower and the lowest value (38.63 g) was obtained in the control treatment. Gunnes et al. (2003) and Khan et al. (2006) found that boron application significantly increased 1000 grain weight in wheat compared to control.

Cultivars had significant effects on seed yield ($p<0.05$) and Karakız cultivar had the highest value with 105.19 kg da^{-1} (Table 4). The seed yield was significantly affected by boron application and the highest seed yield was obtained from 200 and 300 mg L^{-1} boron application (91.45 and 93.85 kg da^{-1}, respectively). In the cultivar × boron interaction, seed yield values varied between 65.99-113.09 kg da^{-1}, but this difference was not found statistically significant ($p>0.05$). Seed yield in linseed is closely related to its yield components. Yield components are affected by both genetic and environmental conditions. The seed yield is positively correlated with the number of capsules per plant, number of seeds per capsule and 1000 seed weight (Çopur et al., 2006; Ibrar et al., 2016). In oilseed flax, seed yield was reported by Tunçtürk (2007) 99.7-149.0 kg da^{-1}, Tanman (2009) 118.6-175.6 kg da^{-1}, Endes (2010) 65.30-124.10 kg da^{-1}, Katar et al. (2023) 109.0-212.0 kg da^{-1}. Alam et al. (2020) found that foliar application of 0.5% $ZnSO_4$ with 0.3% Borax 45 days after sowing significantly increased seed yield in both years compared to the control (129.9 and 133.5 kg da^{-1}). Bungla et al. (2021) reported that boron application significantly increased seed yield in linseed and that the positive interaction between boron and sulfur significantly and synergistically affected seed yield of linseed. The high doses of boron significantly increased seed yield in safflower and the highest seed yield were obtained in 500 g da^{-1} boron application (Katar et al., 2014). The results confirm the findings of earlier researchers.

Cultivars and boron applications did not affect the oil content statistically significantly ($p>0.05$). Although the highest oil content was obtained from Sarı Dane cultivar of 300 mg L^{-1} boron application (36.22%), this value was not found to be statistically significant. Yıldırım & Arslan (2013) and Arslan & Culpan (2021) reported that the oil content in linseed varied between 29.83-34.08% and 33.76-36.15%, respectively. In addition, some researchers found that different boron doses relatively increased the oil content in oilseeds, but this was not statistically significant (Nasef et al., 2006; Katar et al., 2014). These results are consistent with our findings. Differences in oil content among the cultivars examined can be attributed to the genetic and genomic diversity present in their overall genetic make-up (Ibrar et al., 2016).

Cultivars had significant effects on oil yield ($p<0.05$) and Karakız cultivar had the highest value with 37.80 kg da^{-1} (Table 4). The seed yield was significantly affected by boron application and the highest seed yield was obtained from 200 and 300 mg L^{-1} boron application (32.78 and 33.65 kg da^{-1}, respectively). In the cultivar × boron interaction, seed yield values varied between 23.57-40.56 kg da^{-1}, but this difference was not found statistically significant ($p>0.05$). Oil yield is calculated based on seed yield and oil content (Cvejić et al., 2023). The increase in seed yield or oil content directly affects oil yield. Boron applications positively affected seed yield (Rawashdeh & Sala, 2014; Beyzi et al., 2019; Bungla et al., 2021; Khuong et al., 2022) and therefore oil yield was also positively affected. The oil yield values we obtained as a result of the research were within the limits specified by Endes (2010) 21.9-39.6 kg da^{-1}, Lemessa and Zerihun (2022) 42.20-69.59 kg da^{-1}, Katar et al. (2023) 37.0-77.0 kg da^{-1}.

4. Conclusion

Application of boron at a concentration of 200 and 300 mg L^{-1} at 45 DAS helped to increase yield and quality parameters of plant height, branch number, number of capsules per plants, number of seeds per capsule, seed yield and oil yield of linseed. The positive effect of boron applications on yield components led to an increase in seed yield. In particular, seed yield increased by 16.12% and 19.17% at 200 and 300 mg L^{-1} doses, respectively, compared to the control. Therefore, the increase in seed yield directly affected the oil yield. In conclusion, foliar application of appropriate doses of boron contributes to increase the yield of linseed, especially in medium and low input farming systems.

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