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Title: Nitrogen Use Efficiency of Boro Rice Varieties (*Oryza sativa* L.) Using Different Sources of Nitrogen Fertilizer

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ABSTRACT

Nitrogen Use Efficiency (NUE) integrates nitrogen (N) in different crop parts and depends upon the sources from which it derives. Higher NUE is essential for high yield potential and minimizing N loss after addition in soil. For this, a pot experiment was set up to evaluate the NUE of three boro rice varieties which are BRRI dhan61, BRRI dhan68, and BRRI dhan28 considering two sources of commercial urea fertilizer. These sources were termed as T1 (Urea, Kingdom of Saudi Arabia origin) and T2 (Urea, Qatar origin) while the control treatment was designated as T0. All the pots were arranged in a completely randomized design with four replications. Various NUE parameters such as partial factor productivity (PFP), crop recovery efficiency (CRE), agronomic efficiency (AE) and physiological efficiency (PE), agronomic as well as yield contributing characteristics of rice were studied. Results indicated that T1 showed the highest PFP, CRE, and AE in BRRI dhan68 which were 34.43 kg kg^{-1}, 0.70 kg kg^{-1}, and 26.32 kg kg^{-1}, respectively, whereas the highest PE (81.58 kg kg^{-1}) was observed in BRRI dhan28 with T2. All the rice varieties showed the highest nitrogen uptake by grain when treated with T1. Maximum grain yield (30.99 g pot^{-1}) was found in BRRI dhan68 in T1 treated soil, which increased by 13.65% and 33.11% from BRRI dhan61 and BRRI dhan28, respectively. Agronomic as well as yield contributing characteristics such as height, tiller per plant, panicle per plant, straw yield, etc. were also highest in T1-treated soil irrespective of the rice plant studied. Considering the results of this experiment, it can be concluded that T1 treatment has a relative advantage compared to T2 used as nitrogen fertilizer sources because it enhanced N use efficiencies and may lead to reduced N losses in rice production.

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INTRODUCTION

Nitrogen (N) is a crucial nutrient that influences the quality, yield, growth, and development of crops, while also representing a substantial part of the costs associated with crop production (Wang et al., 2020; Liu et al., 2023). The advancement of rice cultivation is significantly hindered by excessive nitrogen input and low nitrogen use efficiency (NUE). NUE indicates a plant's capacity to absorb, assimilate, translocate, and reuse nitrogen, and is influenced by various factors, including fertilizer properties, varietal traits, soil and crop management practices, and environmental conditions (Fageria et al., 2008; Zhong et al., 2017; Ferdous et al., 2019; Tang et al., 2019; Madaline et al., 2021; Huang et al., 2022). N is the most critical limiting element influencing grain yield and is required by rice in larger quantities than any other nutrient (Hou et al., 2019). Adequate N is essential during the early growth, mid-tillering, and panicle initiation stages to ensure optimal grain development and maximize crop yield (Ahmed et al., 2005; Iqbal, 2011). Farmers apply excessive N to enhance crop productivity. N inputs are associated with improved yields, but the overall efficiency of N utilization remains inadequate. The improvement of rice varieties has significantly increased rice yield globally. In particular, nutrient-efficient genotypes may produce higher yields per unit of nutrient intake when cultivated in the same agroecologies as conventional genotypes (Zhou et al., 2016).

The worldwide rice production increased from 216 Mt in 1961 to 769 Mt in 2020 (FAOSTAT, 2023). Bangladesh yearly produces 37.6 million metric tons of rice, cultivated across 11.70 million hectares of land (BBS, 2022). About 50% of global N fertilizer is applied to major cereals of which approximately 16% is allocated for rice growth (Heffer et al., 2017). But the global NUE remained below 40% (Omara et al., 2019) indicating that more than 60% of applied N remains unused or is lost from soil (Dobermann, 2000; Ladha et al., 2005). In order to improve and maximize the NUE in rice, it is essential to apply N fertilizers from sources, which boosts yields while reducing production costs and environmental pollution.

Enhanced efficiency of N fertilizers is being continuously developed to control the release of the element from fertilizers (Barman et al., 2020). Despite having a significant effect on NUE in rice cultivation, the efficiency of commercial N fertilizers is unenlightened. In Bangladesh, there are lots of commercial N fertilizers available in the market. Two of the most used commercial N fertilizers by farmers are urea of Saudi Arabia and Qatar origin. However, there is limited research on the quantitative findings of NUE from these two sources of nitrogenous fertilizers for rice growth. The aim of this research is to identify the potentiality of N fertilizer sources in terms of their NUE when applied to boro rice varieties in Bangladesh.

MATERIALS AND METHODS

Experimental Site and Soil

From January to May 2023, a pot experiment was carried out in a net house of Soil, Water and Environment Discipline, Khulna University. The soil sampling site is located at 22◦48′ 7.587″ N latitude and 89◦32′ 11.588 E longitude which falls under the AEZ of the Ganges tidal floodplain. After collection, the soil was air-dried, ground, and sieved through a 2 mm sieve. Initial soil physical and chemical properties were determined by the standard methods before the experiment (Table 1) before rice transplantation.

Table 1. Physical and chemical properties of soil and fertilizer before rice transplantation

Characteristics	Values	Methodology	Reference
Textural class	Clay loam	Hydrometer method	Gee and Bauder (1979)
pH (soil-water ratio 1:2.5)	6.80	Soil-water ratio of 1:2.5	Jackson (1973)
EC (dS m^{-1}) (soil-water ratio 1:5 at 25 °C)	1.15	Soil-water ratio of 1:5	USSLS (1954)
Soil organic matter (SOM) (%)	1.83	Wet oxidation method	Walkley and Black (1934)
Total N (%)	0.56	Kjeldahl method	Bremner and Mulvaney (1982)
Available N (ppm)	1139.60	Kjeldahl method	Bremner and Mulvaney (1982)
Available P (μg/g)	14.84	Molybdophosphoric blue color method with olsen extraction	Murphy and Riley (1962)
Total P (μg/g)	728.75	Vanado molybdophosphoric	Jackson (1973)

Characteristics	Values	Methodology	Reference
		yellow color method	
Available S (μg/g)	178.40	Turbidimetric method	Jackson (1973)
Exch + WS K^+ (cmol(+)/kg)	0.67	Flame photometric method	Kundsen et al. (1982)
Exch + WS Ca^{2+} (cmol(+)/kg)	8.52	Flame photometric method	Lanyon and Heald (1982)
Exch + WS Mg^{2+} (cmol(+)/kg)	3.40	Flame photometric method	Lanyon and Heald (1982)
Exch + WS Na^+ (cmol(+)/kg)	0.71	Flame photometric method	Kundsen et al. (1982)
CEC (cmol(+)/kg)	13.31	Flame photometric method	Jackson (1973)
Total N % (Urea, Saudi Arab)	41.47	Kjeldahl method	Jackson (1973)
Total N % (Urea, Qatar)	38.33	Kjeldahl method	Jackson (1973)

Experimental Setup and Cultural Operations

The pot experiment was carried out in a completely random design (CRD) with four replications. There was a total of thirty-six earthen pots [Treatment (3) × Variety (3) × Replication (4) = 36]. Each pot had a diameter of 26 cm with a capacity of 5 kg of soil. The two treatments with control were considered in the experiment which was termed as T1 (Urea, Kingdom of Saudi Arabia origin) and T2 (Urea, Qatar origin). Pots that received no urea fertilizer were treated as control (T0). Three boro rice varieties were selected for cultivation which are BRRI dhan61, BRRI dhan68 and BRRI dhan28. All of the pots received the necessary nutrient sources as a base application of MoP (77 kg ha^{-1} K), DAP (24 kg ha^{-1} P), Gypsum (18 kg ha^{-1} S), Zinc Sulfate (2.6 kg ha^{-1} Zn), and Urea (180 kg ha^{-1} N) at the time of soil preparation according to Fertilizer Recommendation Guide (2018). Urea was applied in 3 split doses (33% before transplanting, 34% at 35 days after transplanting, and 33% at the panicle initiation stage (Ahmed et al., 2018). The 40-days-old seedlings were transferred into pots. The number of hills per pot was one, and the number of seedlings for each hill was two. For cultural operations, proper crop management procedures including irrigation and weeding were followed throughout the growing period and kept similar across all experimental pots. During the experiment, each pot was kept at a constant level of 3 to 5 cm of water until 2 days before the harvest. At ripening phase, plants were harvested, and afterward, the cut crops were threshed, winnowed, cleaned, and packed separately for laboratory analyses.

Plant Analysis: Growth and Yield

In this experiment, plant height (PH), number of tillers $hill^{-1}$ (TN), number of filled grains $panicle^{-1}$ (FG), number of unfilled grains $panicle^{-1}$ (UFG), number of total grains $hill^{-1}$ (TG), and 1000 grain weight (1000-G weight) data of rice were recorded. The grain yield (GY), straw yield (SY), and biological yield (BY) were estimated on a g pot^{-1}. Besides that, the harvest index HI was calculated according to Equation 1;

$$\text{Harvest index (HI) (\%)} = \frac{GY}{GY + SY} \times 100 \quad \text{----} (1)$$

Plant Analysis: Nitrogen Concentration and Uptake

The harvested plant samples were oven-dried at 60℃ for 24 hours. The dried root, straw, and grain were then weighted and ground. To determine the N content, the samples were digested with H2SO4 plus HClO4 (Nelson and Sommers, 1973). The N by the Kjeldahl method (Bremner and Mulvaney, 1982), After that, we calculated nitrogen uptake (kg ha^{-1}) parameters based on nutrient content (%) and dry matter yield (kg ha^{-1}) using Equation 2;

Nitrogen uptake (kg/ha) = $\frac{\text{Nitrogen content (\%)} \times \text{Dry matter yield}}{100}$ ---- (2)

Nitrogen Use Efficiency Parameters

Partial factor productivity (PFP), agronomical efficiency (AE), physiological efficiency (PE), and crop recovery efficiency (CRE) were measured according to Equations 3, 4, 5 and 6 (Dobermann, 2005);

PFP (kg kg^{-1}) = Yield /Unit fertilizer applied ---- (3)
AE (kg kg^{-1}) = Yield increase/Unit nutrient applied ---- (4)
PE (kg kg^{-1}) = Yield increase/Increase in unit fertilizer nutrient uptake ---- (5)
CRE (kg kg^{-1}) = Increase in unit fertilizer nutrient uptake/Unit fertilizer applied ---- (6)

Statistical Analysis

The data were analyzed statistically using a two-way analysis of variance (ANOVA) at a 5 % confidence level to examine whether the effects were significant. The Tukey Tests (Gomez and Gomez, 1984) were done to verify the difference between pairwise treatments by Statistix 10.0 (2013).

RESULTS AND DISCUSSION

Agronomic parameters

Plant height varied from 65.47 (T0) to 103.44 (T1) cm. The application of two different commercial urea fertilizers showed a significant effect on the plant height of three boro rice varieties ($p < 0.05$). Between T1 and T2 a maximum plant height of 103.44 cm was observed in T1 applied BRRI dhan68 whereas the minimum plant height of 75.63 cm was attained in T2 applied BRRI dhan28.

Table 2. Interaction effect of two commercial N fertilizers on plant height (PH), tiller number hill−1 (TN), number of filled grains panicle-1 (FG), number of unfilled grains panicle-1 (UFG), and 1000-grains weight of three boro rice varieties

Varieties	N source	PH (cm)	TN	FG	UFG	1000-Grain Weight (g)
BRRI dhan61	T_1 (Urea, Saudi Arab)	93.47±4.37b	14.25±1.71a	144.71±7.84abcd	44.38±7.23ab	20.14
	T_2 (Urea, Qatar)	88.46±2.65bc	12.25±2.63ab	141.41±6.19bcd	45.22 ±4.02ab	20.12
	T_0 (Control)	79.12±3.44d	6.25±0.50c	135.88±2.99cd	45.29±3.78 ab	20.12
BRRI dhan68	T_1 (Urea, Saudi Arab)	103.44±1.85a	14.25±2.06a	159.27± 5.42a	46.18 ±3.75ab	20.11
	T_2 (Urea, Qatar)	94.36±4.85b	10±1.15b	154.99 ± 7.43ab	54.00 ±5.21 a	20.12
	T_0 (Control)	82.23±1.12cd	6 ±1.15d	146.46 ±8.23abc	42.38 ±4.30ab	20.14
BRRI dhan28	T_1 (Urea, Saudi Arab)	77.28±3.93d	10±0.82b	154.17± 10.86ab	48.10±1.65 ab	18.20
	T_2 (Urea, Qatar)	75.63 ±1.37d	9.75± 0.96bc	151.91 ± 8.06abc	41.88 ±1.84b	18.18
	T_0 (Control)	65.47± 0.64e	4.25±0.96d	127.50 ± 5.98d	41.88 ±1.95 b	18.15

In each column, the means ± standard deviation values denoted by the same letter are not significantly different at the p<0.05 level

Islam et al. (2016) discovered a similar response in plant height in boro rice cultivation. They indicated that plant growth can be affected by different N rates and sources. Furthermore, the number of tillers varied significantly across treatments (p <

0.05). The highest number of tillers hill-1 was 14.25 from T1 applied both BRRI dhan61 and BRRI dhan68 variety and the lowest number of tillers hill-1 was 4.25 from T0 applied BRRI dhan28. T1 applied all three varieties showed comparatively higher tiller numbers than T2 applied varieties. Effective tiller number also significantly varied with the treatments ($p < 0.05$). T2 applied all three varieties showed comparatively lesser effective tiller numbers than T1 applied varieties.

Consequently, the number of panicles and filled grains panicle^{-1} were significantly affected by the treatments Amanullah et al. (2020) applied different organic nitrogen sources and found variations in plant growth parameters. Without considering T0 treatment, the result showed that the application of two different commercial urea fertilizers did not have any significant effect on the unfilled grains panicle^{-1} of three boro rice varieties. The application of various urea sources led to a comparable response in the rice plants' filled grains panicle^{-1} (Khatun et al., 2015). The experiment demonstrated that the 1000-grain weight of rice varieties was unaffected by the type of nitrogen fertilizer used. However, there was a significant change in the 1000-grain weight among different varieties ($p<0.05$). BRRI dhan28 showed a significantly lower 1000-grain weight than BRRI dhan61 and BRRI dhan68. Karki et al. (2018) and Amanullah et al. (2020) also found a similar response in the 1000-grain weight of rice plants due to the different methods of urea application as they did not find any variations in 1000-grain weight.

Grain Yield and Straw Yield

Yield production significantly varied with the treatments ($p < 0.05$). The highest amount of grain yield was 30.99 g pot^{-1} from T_1 applied BRRI dhan68 which was increased by 13.65% and 33.11% from BRRI dhan61 and BRRI dhan28 of the same treatment (T_1) respectively. The lowest number of yield production was 5.77 g pot^{-1} from T_0 applied BRRI dhan28. T_1 applied all three varieties showed comparatively better grain yield than T_2 applied varieties. There was a prominent variation in yield across different urea source applications in rice cultivation, which was observed by Mi et al. (2017). Moreover, the Highest straw yield was 57.05 g pot^{-1} from T_1 applied BRRI dhan68 which was increased by 14.65% and 18.67% from BRRI dhan61 and BRRI dhan28 of the same treatment (T_1) respectively. The lowest number of straw yield production was 33.34 g pot^{-1} from T_0 (Control) applied BRRI dhan28. However, there are several mixed opinions on the impact of different nitrogen sources on straw yield. However, different nitrogen levels affect straw yield. An experiment conducted by Jahan et al. (2022) also observed significant variations in the straw yield production in rice plants by applying different rates of nitrogen fertilizer.

Harvest Index

The harvest index significantly varied with the treatments of urea on rice production ($p<0.05$). The highest harvest index was 35.40% from T_1 applied BRRI dhan61 and the lowest harvest index was 14.58% from T_0 applied BRRI dhan28. Although between T_1 and T_2, there is no significant effect was found as each treatment had a value that was statistically similar at Tukey test analysis in a 95% confidence level. Roy et al. (2022) conducted a yield monitoring experiment in northern Bangladesh, where the highest harvest index (54.84%) was found in BRRI dhan74 cultivation.

Table 3. Interaction effect of two commercial N fertilizers on grain yield (GY), straw yield (SY), harvest index (HI), grain nitrogen uptake (GNU), and straw nitrogen uptake (SNU) parameter of three boro rice varieties

Varieties	N source	GY (g pot^{-1})	SY (g pot^{-1})	HI (%)	GNU (kg ha^{-1})	SNU (kg ha^{-1})
BRRI dhan61	T_1 (Urea, Saudi Arab)	26.76±2.16ab	48.69 ±1.85b	35.40±2.49a	80.78±15.03b	28.51±3.63ab
	T_2 (Urea, Qatar)	21.81±0.42bc	41.05±2.61cd	34.62±4.86a	45.67±14.96cd	22.17±3.92b
	T_0 (Control)	8.84± 1.37d	33.62 ±3.35d	20.76±1.49b	2.01±0.33e	4.49±0.27c
BRRI dhan68	T_1 (Urea, Saudi Arab	30.99 ± 1.85a	57.05±3.30a	35.23±2.89a	127.61 ± 9.34a	33.78±6.72a
	T_2 (Urea, Qatar))	22.40±0.51bc	41.87±2.85cd	34.87±3.63a	60.91±11.84bc	21.74±2.65b
	T_0 (Control)	7.30 ± 0.33d	34.62 ±3.80 d	17.45±3.65b	1.72 ± 0.40e	5.71±2.77c
BRRI dhan28	T_1 (Urea, Saudi Arab)	20.73± 0.20c	46.40±1.85bc	30.90±1.01a	49.39 ±5.19cd	25.93±2.48ab
	T_2 (Urea, Qatar)	19.80±1.18c	40.10±1.68cd	33.04±0.75a	35.31 ± 5.17d	21.18± 2.41b
	T_0 (Control)	5.77±1.43d	33.34±3.18d	14.58±2.39b	1.34 ± 0.37 e	4.35±0.55c

In each column, the means ± standard deviation values denoted by the same letter are not significantly different at the $p < 0.05$ level

N Uptake by Grain and Straw

The highest amount of N uptake by grain was 127.61 kg ha^{-1} from T_1 applied BRRI dhan68 which was increased by 36.70% and 61.30% from BRRI dhan61 and BRRI dhan28 of the same treatment (T_1) respectively. T_2) applied BRRI dhan68 showed a 52.27% decrease in N uptake by grain from T_1 applied BRRI dhan68. The lowest grain N uptake was 1.34 kg ha^{-1} from T_0 applied BRRI dhan28. T_1 applied all three varieties showed significantly better grain N uptake than T_2 applied varieties. According to Singh et al. (2014), the grain nitrogen uptake was significantly varied due to the different sources of urea which is similar to our results as there is a highly significant effect was found in the grain N uptake between two of our sources. Moreover, the analysis showed that N uptake by straw significantly varied with the treatments ($p < 0.05$). The highest amount of N uptake by straw was 33.78 kg ha^{-1} from T_1 applied BRRI dhan68 which was increased by 15.6% and 23.24% from BRRI dhan61 and BRRI dhan28 of the same treatment (T_1) respectively. T_2-applied BRRI dhan68 showed a 35.64% decrease in N uptake by straw from T_1-applied BRRI dhan68. The lowest straw N uptake was 4.35 kg ha^{-1} from T_0 (Control) applied BRRI dhan28. Dash et al. (2011) also reported that N uptake in straw and total N uptake had a significant quadratic response to N fertilization sources.

Table 4 Interaction effect of two commercial N fertilizers on partial factor productivity (PFP), crop recovery efficiency (CRE), agronomic efficiency (AE), and physiological efficiency (PE) parameter of three boro rice varieties

Varieties	N source	PFP (kg kg^{-1})	AE (kg kg^{-1})	PE (kg kg^{-1})	CRE (%)
BRRI dhan61	T_1 (Urea, Saudi Arab)	29.73 ± 3.37ab	19.91±3.37b	45.05 ± 1.60de	44.35 ±8.35b
	T_2 (Urea, Qatar)	24.23±3.93bc	14.40±3.93b	59.17± 6.64bc	24.85 ±8.31cd
BRRI dhan68	T_1 (Urea, Saudi Arab)	34.43±2.43a	26.32±2.43a	37.31± 1.18 e	70.49 ±5.19a
	T_2 (Urea, Qatar)	24.89±2.74bc	16.78 ±2.74b	50.46± 3.32cd	33.43 ± 6.58bc
BRRI dhan28	T_1 (Urea, Saudi Arab)	23.04 ±0.71c	16.63±0.71b	61.82± 5.78b	27.07 ± 2.88cd
	T_2 (Urea, Qatar)	22.00 ± 1.41c	15.59±1.41b	81.58 ± 6.22 a	19.25 ± 2.87d

In each column, the means ± standard deviation values denoted by the same letter are not significantly different at the $p < 0.05$ level.

Partial Factor Productivity (PFP)

The PFP of grain significantly varied with the treatments ($p < 0.05$). The highest amount of PFP of grain was 34.43 kg kg^{-1} from T_1 applied BRRI dhan68 which was increased by 13.65% and 33.08% from BRRI dhan61 and BRRI dhan28 of the same treatment (T_1), respectively. T_2 applied BRRI dhan68 showed a 27.71% decrease in the PFP of grain from T_1 applied BRRI dhan68. The lowest PFP of grain was 22 kg kg^{-1} from T_2 applied BRRI dhan28. Ahmed et al. (2018) found a comparative response in partial factor productivity with different application methods of nitrogen fertilizers in boro rice cultivation.

Agronomic Efficiency (AE)

Grain's AE varied significantly with the treatments in the experiment ($p < 0.01$). The optimal amount of AE of grain was 26.32 kg kg^{-1} (T_1 applied BRRI dhan68); this was raised by 24.35% and 36.22%, respectively, from BRRI dhan61 and BRRI dhan28 of the same treatment (T_1). T_2 applied BRRI dhan68 showed a 36.25% decrease in the AE of grain from T_1 applied BRRI dhan68. The minimum AE of grain was 14.40 kg kg^{-1} from T_2 applied BRRI dhan61. The results are also consistent with the findings of Chen et al. (2020) and Rahman et al. (2009).

Physiological Efficiency (PE)

The highest amount of PE of grain was 81.58 kg kg^{-1} from T_2 applied BRRI dhan28 which was increased by 27.47% and 38.15% from BRRI dhan61 and BRRI dhan68 of the same treatment (T_2) respectively. T_1 applied BRRI dhan28 showed a 24.22% decrease in the PE of grain from T_1 applied BRRI dhan68. The lowest PE of grain was 37.31 kg kg^{-1} from T_1 applied BRRI dhan68. Bhuiyan et al. (2016) found the highest agrophysiological efficiency (84 kg kg^{-1}) in BRRI dhan29 with nitrogen application from USG by the USG applicator.

Crop Recovery Efficiency (CRE)

From the analysis, the highest amount of CRE of grain was 70.49% from T_1 applied BRRI dhan68 whereas the lowest CRE of grain was 19.25% from T_2 applied BRRI dhan28. T_1 applied all three varieties showed significantly better results in the CRE of grain than T_2 applied varieties. The findings are in line with the results reported by Islam et al. (2016).

CONCLUSION

This study showed the effectiveness of two urea fertilizers, such as urea from Saudi Arabia (T1) and urea from Qatar (T2), which are frequently used by Bangladeshi farmers. For this purpose, three types of boro rice (BRRI dhan61, BRRI dhan68, and BRRI dhan28) were used. The findings revealed that T1 has a relative advantage in comparison with T2 due to enhanced nitrogen use efficiencies which may lead to reduced N losses in rice production. BRRI dhan68 showed greater nitrogen use efficiency (NUE) with the application of T1 as it showed the highest partial factor productivity (PFP), agronomic efficiency (AE), and crop recovery efficiency (CRE) in both grain and straw. BRRI dhan28 showed the highest physiological efficiency (PE) in grain with the application of T2. Moreover, BRRI dhan68 showed the optimum grain yield, straw yield, and nitrogen uptake with the application of T1. On the other hand, a positive relation was found between grain yield and nitrogen uptake. There was no significant variation in 1000 grain weight and harvest index with the application of urea sources. Agronomic characteristics such as height, tiller per plant, panicle per plant, etc., were also improved in rice varieties when they were treated with T1. Therefore, it can be recommended to use urea from Saudi Arabia origin to increase the efficiencies of the nutrient element during the cultivation of BRRI dhan68.

Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this article.

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