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Research article

Physiological and productive response of Vigna radiata L. to the NPK levels and boron foliar application

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A B S T R A C T

A field experiment was applied at College of Agriculture, University of Wasit, 2025. The aim of study was to determine the effect of different levels of NPK and boron applied as a foliar spray on mungbean (*Vigna radiata* L.). The NPK concentration (20-20-20) was used in treatments (F0-F3) at concentrations of (0-10-20-30) ml/L, while the boron concentration (B0-B3) was used in treatments (B0-B3) at concentrations of (0-50-100-150) ml/L. The RCBD experiment was designed as a factorial experiment. The results showed that the highest average concentrations were 30 ml/L for grain yield, biological yield, yield index, and the percentages of nitrogen, phosphorus, and potassium in the leaves (2.442 t ha^{-1}, 4.221 t ha^{-1}, 87.27%, 2.842%, 0.481%, and 1.955%, respectively). The highest results were recorded for foliar boron application at a concentration of 150 ml/L for grain yield, biological yield, yield index, and leaf nitrogen, phosphorus, and potassium content (1.824 t ha^{-1}, 2.727 t ha^{-1}, 77.26%, 2.587%, 0.440%, and 1.76%, respectively). These results allowed researchers to identify how plant growth indicators change when using different levels of NPK nanofertilizers and to determine the interaction effect of NPK nanofertilizers and boron on growth indicators and yield enhancement, ultimately identifying the optimal and most cost-effective formulation.

1. Introduction

Nanofertilizers are extremely small particles that release nutrients precisely and slowly. These nutrients are then delivered to the plant at precisely the right time via a biological mechanism. These fertilizers provide nutrients throughout the growing season and reduce the environmental risks associated with traditional fertilizers. They supply plants with essential nutrients, earning them the name "smart fertilizers," and are available in various forms, including single- and multi-format formulations. Their role is to enhance the effectiveness of traditional fertilizers and improve crop yields (Pramanik et al., 2020). Although farmers have relied primarily on chemical fertilizers to increase crop production, excessive use and unbalanced NPK ratios have caused numerous soil problems, such as salt accumulation and reduced organic matter, in addition to negative

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environmental impacts (Upadhyay et al., 2023). Fertilizers provide nutrients in chemical forms that are difficult for plants to absorb easily.

Most of the macronutrients added by these chemical fertilizers are poorly soluble in the soil, resulting in very low utilization. Consequently, frequent application of these chemical fertilizers is required, leading farmers, driven by increasing food demand, to use more of them. This negatively impacts soil health and the environment. As a result of excessive fertilizer use, soil structure and mineral cycles suffer irreversible damage. Furthermore, the overuse and inappropriate application of fertilizers harms soil and plant microorganisms, ultimately disrupting food chains in ecosystems and leading to genetic mutations in future generations. Nitrogen (N) and phosphorus (P) fertilizers have been identified as major human-caused factors contributing to global problems (Kumar, 2020).

Boron is an inorganic element and one of the most important elements in fertilizers. Although plants require it in small amounts, it is essential. It helps in the movement and transport of materials necessary for photosynthesis from the leaves to other parts of the plant (Ahmad et al., 2009). Boron plays a pivotal role in phloem formation, which affects stem and root growth. It also helps plants absorb water and enhances their drought resistance. Boron is added to facilitate nitrogen fixation and the formation of effective root nodules in legumes (Noor and Hossain 2007). Boron supplementation has a significant positive effect on both the reproductive and vegetative stages of mungbean cultivation (Kassab 2005; Quddus et al. 2011). Furthermore, boron improves the uptake of nutrients such as nitrogen, phosphorus, and potassium (Bassil et al. 2004), and it enhances yield, growth rate, and protein levels in mungbean crops (Kaisher et al. 2010).

Mungbean (*Vigna radiata.* L) are an important food source for humans due to their high protein content (up to 29%). They are rich in the amino acid lysine, which is often deficient in many cereal crops. It exhibits high growth potential in diverse environments and is cultivated for use as green fodder for animals and green manure to improve soil fertility and properties (El-Fahdawy et al., 2020). Therefore, the aim of study was determine the effect of different levels of NPK and boron applied as a foliar spray on mungbean (*Vigna radiata* L.).

2. Materials and Methods

A field experiment was done at the College of Agriculture, University of Wasit, during the autumn season of 2024-2025 Planting was on August 10, 2025. Soil samples were collected before planting for analysis of their physical and chemical properties (Table 1). The experiment was conducted using a randomized complete block design (RCBD) as a two-factor experiment. The first factor was applied at four levels (0, 10, 20, and 30 ml/L), numbered (F0–F3). The second factor was applied at four concentrations (0, 50, 100, and 150 ml/L), numbered (B0–B3). The chemical composition of the nano-fertilizer (N,P2O5,K2O) is 1 liter in a liquid form. It is of Turkish origin and manufactured by Agrisens. This nano-fertilizer was applied by foliar spraying once during the elongation stage of the crop, with each concentration diluted in 1 liter of water. Boron was also applied once during the flowering stage, with each concentration diluted in 1 liter of water, in the early morning before sunrise. Three replicates were performed for each treatment. The field was divided into 48 experimental units, each measuring 2 × 2 m^2. Seeds were sown in rows at a rate of 2–3 seeds per hole and thinned after 10 days to one plant per row, with four rows per experimental unit. Irrigation was managed based on 50% field capacity utilization, according to the soil moisture curve.

Eight irrigations were carried out during the season ending November 4, 2025. Chemical fertilizers were applied at half the recommended amount. Concentrated superphosphate (20%

phosphorus) was applied in full at planting, while urea (46% nitrogen) and potassium sulfate (50% K_2SO_4) were applied in two applications: the first two weeks after planting and the second 20 days later. Plant samples of mungbean were collected during the vegetative growth stage, and the necessary nutrients—nitrogen, phosphorus, potassium, and boron—were analyzed. The wet digestion method was used, whereby random plant samples were taken from each experimental unit and washed with ordinary and distilled water to remove dust. The samples were then dried, thoroughly mixed, ground, and placed in paper bags labeled with the treatment numbers. The paper bags were then wrapped in nylon bags to prevent moisture absorption from the air, allowing for the estimation of nutrient concentrations in the plant parts for each experimental treatment.

Table 1. chemical and physical properties before planting

Properties	Units	Value
pH	-	7.22
EC	Dms. m^1	2.30
CEC	centimol kg $soil^{-1}$	12.60
Organic Matter	g kg-1 soil	8.00
Ca^{2+}	m mol. L^{-1}	6.40
Mg^{2+}		4.00
K^+		1.00
Na^+		4.60
Cl^-		7.80
SO_4^{2-}		8.50
CO_3^{2-}		Nil
HCO_3^-		1.60
Nitrogen	Mg.kg $soil^{-1}$	36.4
Phosphorus		13.2
Potassium		75.1
Sand	170 $g.kg^{-1}$	Silty Loam
Silt	720 $g.kg^{-1}$	
Clay	110 $g.kg^{-1}$	

2.1 Measured Crop Characteristics

2.1.1 Grain Yield (tons/ha)

Grain yield was calculated by determining the number of plants using plant density in square meters, then converting to hectares according to the following equation:

Grain yield (tons/ha) = Yield per plant (g) x (number of plants in ha)

2.1.2 Biological Yield (tons/ha)

All plants were taken from a defined area of the experimental unit, then air-dried. The weight of all plant parts was then measured, and the average was calculated.

2.1.3 Yield Index (%)

Calculated according to the equation: Yield Index = Grain Yield ÷ Biological Yield × 100%

2.1.4 Nitrogen Concentration in Plant Samples

Nitrogen concentration in plant samples estimated using the microcalcladal method described by Salem and Ali (2017).

2.1.5 Phosphorus Concentration in Plant Samples

Phosphorus concentration in plant samples estimated in the plant extract according to the method described by Salem and Ali (2017).

2.1.6 Potassium Concentration in Plant Samples

Potassium concentration in plant samples has measured in Plant extract as described by Salem and Ali (2017).

2.2 Statistical Analysis

The data were statistically analyzed after the data collection and tabulation process was carried out and the Genstat program was used with an RCBD design and the means were compared according to the Least Significant Difference (LSD) test at a probability level of 0.05 (Al-Rawi and Khalaf Allah, 1980).

3. Results and Discussion

The highest treatment for spraying nano-fertilizer F3 was 2.442 tons ha^{-1}, and the lowest treatment, F0, was 0.6482 tons ha^{-1}. For boron spraying, the highest treatment, B3, was 1.824 tons ha^{-1}, and the lowest treatment, B0, was 1.434 tons ha^{-1} (Table 2).

Table 2. Effect of Nano-Fertilizer and Boron on Grain Yield of *Vigna radiata* (ton/ha^{-1})

Treatments	**Boron Con.**				**Average**
	B0	**B1**	**B2**	**B3**	
F0	0.516	0.523	0.731	0.821	0.648
F1	1.141	1.334	1.367	1.705	1.387
F2	1.804	1.949	2.045	2.148	1.986
F3	2.277	2.339	2.53	2.622	2.442
Average	1.434	1.537	1.669	1.824	
LSD 0.05	F= 0.033	B= 0.033		F×B=0.067	

Table (3) shows the results of the biological yield, which the highest treatment for spraying nano-fertilizer F3 was 4.221 tons ha^{-1}, and the lowest treatment F0 was 0.995 tons ha^{-1}. As for the average boron spraying, the highest treatment B3 was 2.727 tons ha^{-1}, and the lowest treatment B0 was 1.911 tons ha^{-1}.

Table 3. Effect of nano-fertilizer and boron on biological yield of *Vigna radiata* (ton/ha^{-1})

Treatments	Boron Con.				Average
	B0	**B1**	**B2**	**B3**	
F0	0.785	0.838	1.016	1.342	0.995
F1	1.501	1.556	1.634	2.029	1.680
F2	2.159	2.34	2.443	2.443	2.346
F3	3.198	3.828	4.762	5.095	4.221
Average	1.911	2.14	2.463	2.727	
LSD 0.05	F= 0.062	B= 0.062		F×B=0.124	

The effect of nano-fertilizer and boron on the yield index. The highest average value of nano-fertilizer was recorded for treatment F3 at 4.221%, compared to 0.995% for treatment F0. The average boron value for treatment B3 was 2.727%, compared to 1.911% for treatment B0 (Table 4).

Table 4. Effect of nano-fertilizer and boron on the yield indexof *Vigna radiata* (%)

Treatments	Boron Con.				Average
	B0	**B1**	**B2**	**B3**	
F0	0.7853	0.838	1.016	1.342	0.995
F1	1.501	1.556	1.634	2.029	1.680
F2	2.159	2.34	2.443	2.443	2.346
F3	3.198	3.828	4.762	5.095	4.221
Average	1.911	2.14	2.463	2.727	
LSD 0.05	F= 0.062	B= 0.062		F×B=0.124	

The results in Tables (1, 2 and 3) indicate the highest grain yields were obtained with the 30 ml/L NPK nano-fertilizer. NPK nutrient levels significantly impact seed productivity. These elements are known for their pivotal role in amino acid synthesis, cell number increase, and dry matter accumulation. Improved dry matter accumulation and photosynthetic translocation contribute to increased yield, ultimately leading to higher seed productivity (Waqas et al., 2017). The highest boron value observed with treatment B3 may be attributed to boron's stimulation of cell division and acceleration of photosynthetic translocation (Marschner, 1995).

It also contributes to increased flowering rate and pollen tube growth, thus enhancing pollination and fertilization (Nadian et al., 2010). These findings are consistent with those of Rajput et al. (2018) and Rana et al. (2020) in their research on mustard. This superiority in yield characteristics (grain yield, biological yield, yield index) was noted by Hussein et al. (2019). Phosphorus is a crucial element, ranking second only to nitrogen in terms of the number of pods it produces. It helps plants penetrate deeply into the soil, thus promoting their growth. Phosphorus also contributes to increasing the availability of nutrients and water in the soil, ensuring sufficient water and other nutrients. Adding phosphorus plays a vital role in regulating essential biological processes, increasing yield, promoting root growth, vegetative growth, and early maturity. It is also necessary for flowering and fruit development (Al-Mandalawi, 2002; Al-Issawi, 2024). Furthermore, nano-fertilizers affect plant tissues, activating plant hormones within them, which enhances growth. This may be due to the growth of secondary roots, which positively impacts plant growth and development. The nano-effect may explain the increased yield indicators observed in plants treated with fertilizers (Barandozi et al., 2014). The beneficial and essential role of nitrogen in promoting overall plant growth, particularly in increasing leaf height and area, leads to an increased photosynthetic surface area, thus enhancing nutrient uptake. Manufactured fertilizers require a higher proportion of manufactured nutrients delivered to developing flowers to meet their needs.

These nutrients contribute to fertility, reduce abortions, and consequently increase the number of pods per plant. These elements participate in numerous physiological and biological processes within the plant, such as the synthesis of amino acids and organic acids, and the activation of certain nucleic acids, proteins, chlorophyll, and other compounds. Enzymes contribute to an increase in cell number and size, leading to improved vegetative growth indicators, as the plant receives the necessary nutrients for its growth and development. This, in turn, results in increased flowering and fruit formation in the plant. The direct effect is the provision of essential nutrients that transform vegetative buds into flower buds. Yield indicators include the number of pods, plant productivity, and total yield (Al-Sahaf, 1989), a finding confirmed by Al-Issawi (2024) in an experiment on zucchini plants. The reason for obtaining high values in grain yield, biological yield, and yield index when applying boron foliarly is boron's ability to enhance the plant's efficiency in increasing dry matter and acting as a positive endpoint for treated materials. This positively impacts plant production by increasing the number of seeds per pod or developing fully formed seeds, subsequently leading to an increase in plant yield (Sarhan and Aljumaily, 2015; Pradeep and Elamathi, 2007).

The presence of boron in grains enhances the plant's drought resistance because it regulates the rate of water absorption. It is believed to contribute significantly to increasing carbohydrate content and raising its levels within the plant, in addition to its role in nucleic acid formation, which promotes protein synthesis (Shaaban, 2010). The positive effect of boron on vegetative and root growth can be linked to its positive effect on cellular activity (cell division and elongation) (Al-Arab and Al-Mohamed, 2023; Marschner, 1995; Dugger, 1983).

The interaction between the F3B3 treatment and the F3B3 treatment yielded the highest results in the studied traits. This is attributed to the nano-fertilizer containing essential nutrients necessary for plant growth, which play a crucial role in plant biology. This enhances the efficiency of photosynthesis and increases the amount of nutrients absorbed. Consequently, the amount of nutrients translocated to the plant increases, leading to higher yields (Alshami and Al-Juthery, 2019). Furthermore, boron contributes to increased nutrient levels and enzyme activation, thus promoting protein synthesis and ultimately increasing overall plant yield (Saha et al., 2010).

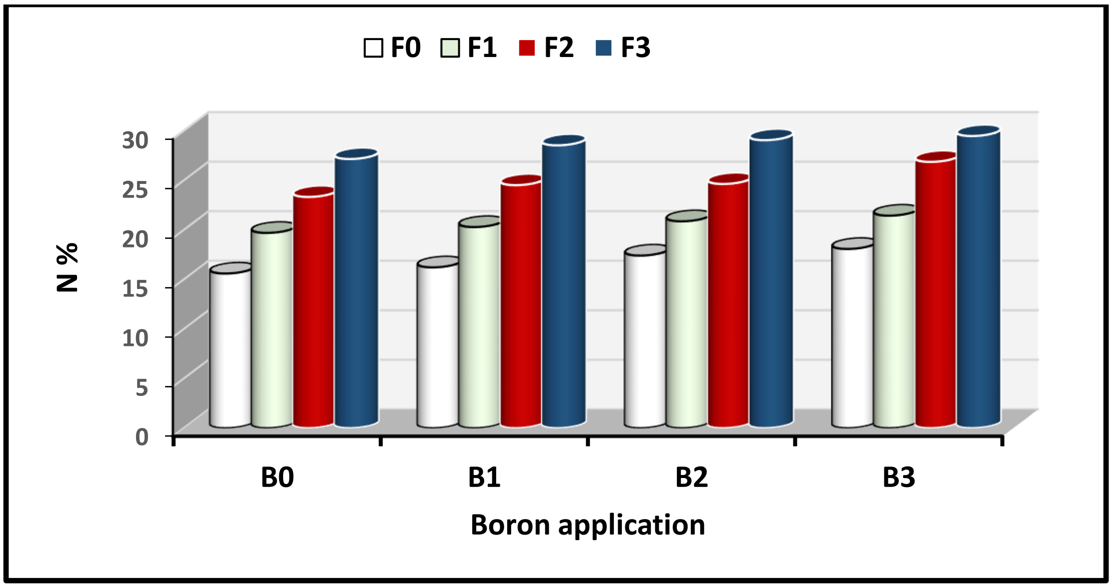

Figure 1. shows the nitrogen percentage in the leaves of *Vigna radiata*

The highest value was recorded in treatment F3 at 2.842%, and the lowest value was recorded in treatment F0 at 1.988%. As for boron, the highest value was recorded in treatment B3 at 2.587%, and the lowest value was recorded in treatment B0 at 2.212%. Figure (2) shows the percentage of phosphorus in the leaves. The highest value was recorded in treatment F3 at 0.481%, and the lowest value was recorded in treatment F0 at 0.334%. As for boron, the highest value was recorded in treatment B3 at 0.440%, and the lowest value was recorded in treatment B0 at 0.387%.

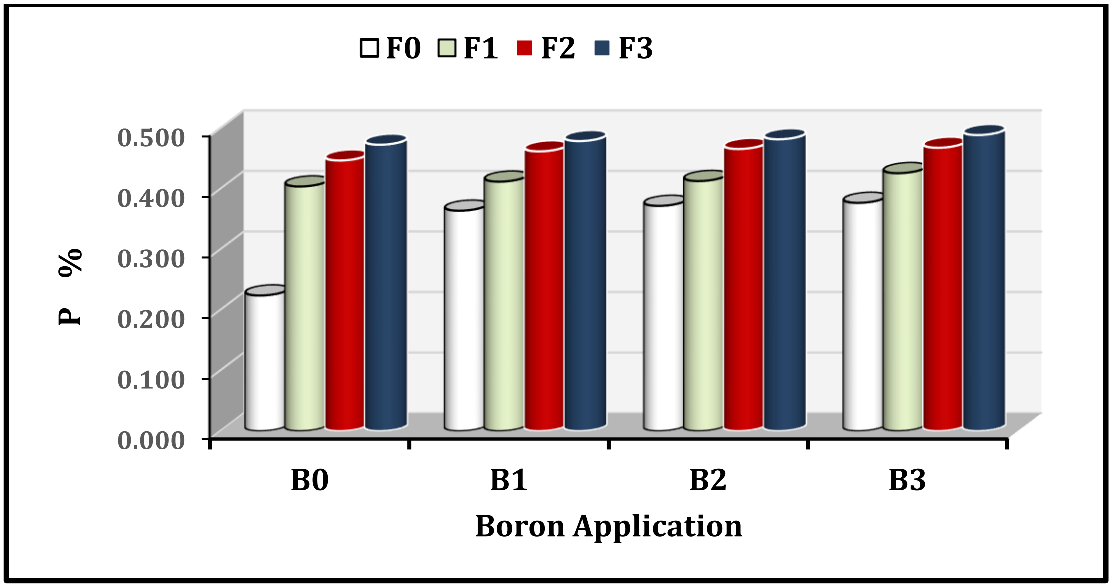

Figure 2. Effect of nano-fertilizer and boron on the percentage of phosphorus in the leaves of *Vigna radiata*

The highest value was recorded in treatment F3 at 1.955%, and the lowest value was recorded in treatment F0 at 1.18%. As for boron, the highest value was recorded in treatment B3 at 1.76%, and the lowest value was recorded in treatment B0 at 1.44% (Figure 3).

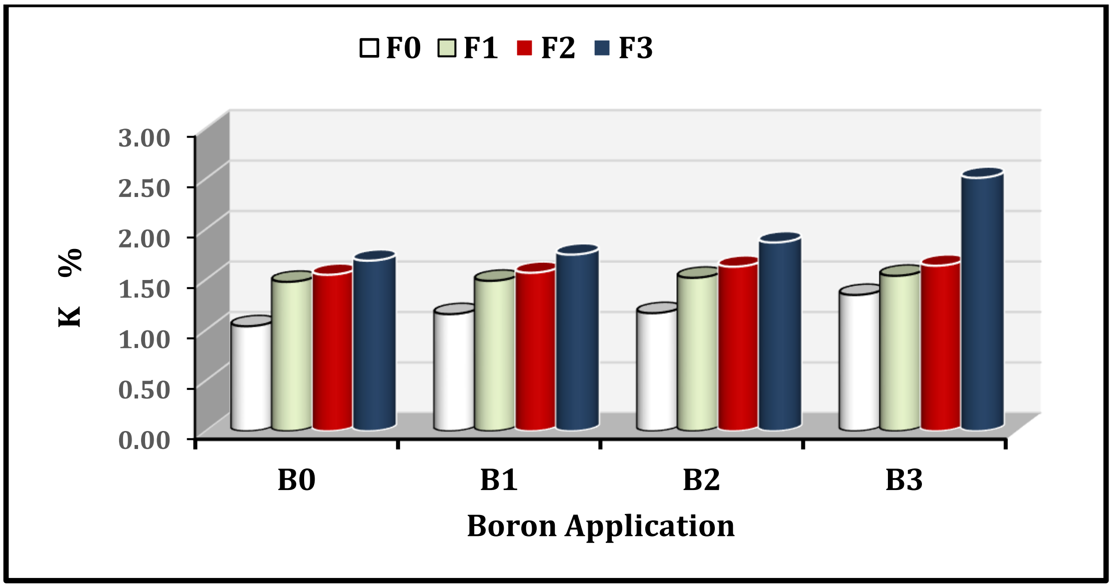

Figure 3. Effect of Nano-Fertilizer and Boron on Potassium Content in Leaves of *Vigna radiata*

The results from Figures (1, 2 and 3) show that the F3 treatment was superior in nitrogen, phosphorus, and potassium. The quantities increased with increasing fertilizer levels. This is attributed to the NPK fertilizer's ability to increase the content of macronutrients in mungbean leaves and transfer them to the soil. This made these elements more available and promoted the growth of a strong root system capable of absorbing them (Al-Fadhli, 2006). Foliar spraying with nano-fertilizers also enabled direct absorption of nutrients, leading to increased concentrations in the leaves. This is likely due to the increased nutrient concentration, which had a positive effect on plant growth. It enhanced the efficiency of photosynthesis and the production of energy needed to absorb nutrients, especially nitrogen, and contributed to root growth and absorption capacity (Shaaban et al., 2006).

Phosphorus significantly contributed to increased nutrient levels in leaves by promoting root growth and enhancing bacterial nodule formation, leading to improved nitrogen fixation and uptake (Singh et al., 2011). Regarding potassium, nano-treatments containing it contributed to increased intraplant concentration, thanks to the effectiveness of foliar spraying. Potassium promotes the active uptake of other nutrients such as nitrogen and phosphorus because it plays a role in regulating osmotic pressure and activating several enzymes necessary for energy production during uptake processes (Khan et al., 2017). The B3 boron foliar spray treatment showed superior nitrogen, phosphorus, and potassium levels in leaves compared to treatment B0. The higher nitrogen content in leaves is attributed to boron's crucial role in nitrogen fixation by rhizobia bacteria. Its role in symbiotic nitrogen fixation within plants was first discovered through studies conducted on broad (*Vicia faba*), and this has been confirmed in other legume species (Long, 2023; Redondo et al., 2003; Bonilla et al., 1997; Bolanos et al., 1994; Brenchley and Thornton, 1925).

Adequate phosphorus levels have been found to increase boron uptake in rapeseed (Brassica napus). This may be due to two factors: (1) phosphorus's ability to enhance water uptake in plants, promoting growth and transpiration, which in turn enhances boron uptake by improving these physiological functions; and (2) phosphorus's ability to influence the biochemical properties of plant roots, making boron more readily available in the soil (Masood et al., 2019). The increased potassium content in the leaves is attributed to potassium promoting boron accumulation, which is particularly important at high boron concentrations. Conversely, high boron concentrations promote potassium accumulation in the roots and leaves of tobacco (Long, 2023; Lopez et al., 2002).

4. Conclusion

The study concludes that adding the highest concentration of NPK nano-fertilizer resulted in significant differences in the studied traits. Foliar application of boron at the highest concentration during the flowering stage yielded significant results. The interaction between the nano-fertilizer and boron in treatment F3B3 was significantly superior to all other treatments in all studied traits.

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