Crushed amygdaloidal basalt rock and its effects on tomato production
Roca basáltica amigdaloidal triturada y sus efectos en la producción de tomate
Rocha basáltica amigdaloide triturada e seus efeitos na produção de tomate

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For cite this article: Dalmora, A., Müller, R., Staubc, J. & Homrich, I. (2022). Crushed amygdaloidal basalt rock and its effects on tomato production. *LADEE*, 3(2), 1–10. https://doi.org/10.17981/ladee.03.02.2022.1

Keywords: Agricultural productivity; Solanum lycopersicum L.; sustainable agriculture; rock dust

Abstract

Introduction: Sustainable agriculture plays an important role in agricultural productivity, in which it seeks to reduce dependence on conventional synthetic fertilizers (imported from Europe) and promote the use of alternative, low-cost and environmentally friendly sources. **Objetive:** An experiment was carried out in the municipality of Santa Maria, Rio Grande do Sul, Brazil, with the objective of evaluating the efficiency and agronomic viability of using a mineral product (amygdaloid basalt powder) as an agricultural input on tomato productivity *Solanum lycopersicum L.* **Methodology:** The experimental design used was randomized blocks with six treatments and four replications, at doses 0 (treatment 1 - control), 1.0-t ha^{-1} of rock dust (treatment 2), 2.5-t ha^{-1} of rock dust (treatment 3), 3.5-t ha^{-1} of rock dust (treatment 4), 4.5-t ha^{-1} of rock dust (treatment 5), and recommended fertilization for tomato 5-20-20 NPK (treatment 6 - standard). **Results:** The treatments were applied in December 2018 and the transplant took place in February 2019. According to the conditions under which the experiment was submitted and analyzing the results obtained, it can be inferred that the application of 1.0-t ha^{-1} of amygdaloidal basalt in the soil increased parameters such as root length, stem diameter, green and dry mass of shoots and roots, number of flowers/plants, number of fruits/plant and productivity in tomato *Solanum lycopersicum L.* **Conclusions:** It is a viable, sustainable, and low-cost strategy that contributes to the achievement of the Sustainable Development Goal (SDG 2) and can be replicated in Brazil and worldwide.

Palabras clave: Agricultura sostenible; polvo de roca; productividad agrícola; Solanum lycopersicum L.

Resumen

Introducción: La agricultura sostenible juega un papel importante en la productividad agrícola, en la que se busca reducir la dependencia de los fertilizantes sintéticos convencionales (importados de Europa) y promover el uso de fuentes alternativas, de bajo costo y amigables con el medio ambiente. **Objetivo:** Se realizó un experimento en el municipio de Santa Maria, Rio Grande do Sul, Brasil, con el objetivo de evaluar la eficiencia y viabilidad agronómica del uso de un producto mineral (polvo de basalto amigdalino) como insumo agrícola sobre la productividad del tomate *Solanum lycopersicum L.* **Metodología:** El diseño experimental utilizado fue bloques al azar con seis tratamientos y cuatro repeticiones, en las dosis 0 (tratamiento 1 - control), 1.0-t ha^{-1} de polvo de roca (tratamiento 2), 2.5-t ha^{-1} de polvo de roca (tratamiento 3), 3.5-t ha^{-1} de polvo de roca (tratamiento 4), 4.5-t ha^{-1} de polvo de roca (tratamiento 5), y fertilización recomendada para tomate 5-20-20 NPK (tratamiento 6 - estándar). **Resultados:** Los tratamientos se aplicaron en diciembre de 2018 y el trasplante se realizó en febrero de 2019. De acuerdo con las condiciones en las que se sometió el experimento y analizando los resultados obtenidos, se puede afirmar que la aplicación de 1-t ha^{-1} de basalto amigdaloidal en el suelo incrementó parámetros como longitud de raíz, diámetro de tallo, masa verde y seca de brotes y raíces, número de flores/plantas, número de frutos/planta y productividad en tomate *Solanum lycopersicum L.* **Conclusiones:** Es una estrategia viable, sostenible y de bajo costo que contribuye a la consecución del Objetivo de Desarrollo Sostenible (ODS 2) y puede ser replicada en Brasil y en todo el mundo.

Palavras-chave: Agricultura sustentável; pó de rocha; produtividade agrícola; Solanum lycopersicum L.

Resumo

Introdução: A agricultura sustentável tem papel relevante na produtividade agrícola, na qual busca reduzir a dependência de fertilizantes sintéticos convencionais (importados da Europa) e promover o uso de fontes alternativas, de baixo custo e ambientalmente amigáveis. **Objeto:** Foi realizado um experimento no município de Santa Maria, Rio Grande do Sul, Brasil para avaliar a eficiência e a viabilidade agronômica da utilização de um produto mineral (pó de basalto amigdalóide) como insumo agrícola na produtividade do tomateiro *Solanum lycopersicum L.* **Metodologia:** O delineamento experimental utilizado foi o de blocos casualizados com seis tratamentos e quatro repetições, nas doses 0 (tratamento 1 - controle), 1.0-t ha^{-1} de pó de rocha (tratamento 2), 2.5-t ha^{-1} de pó de rocha (tratamento 3), 3.5-t ha^{-1} de pó de rocha (tratamento 4), 4.5-t ha^{-1} de pó de rocha (tratamento 5), e fertilização recomendada para o tomate 5-20-20 NPK (tratamento 6 - padrão). **Resultado:** Os tratamentos foram aplicados em dezembro de 2018 e o transplante ocorreu em fevereiro de 2019. De acordo com as condições em que foi submetido o experimento e analisando os resultados obtidos, pode-se inferir que a aplicação de 1.0-t ha^{-1} de pó de basalto amigdaloidal no solo aumentou parâmetros como comprimento da raiz, diâmetro do caule, massa verde e seca da parte aérea e da raiz, número de flores/plantas, número de frutos/planta e produtividade em tomateiro *Solanum lycopersicum L.* **Conclusões:** É uma estratégia viável, sustentável e de baixo custo que contribui para o cumprimento do Objetivo de Desenvolvimento Sustentável (ODS 2) e pode ser replicável no Brasil e no mundo.

DOI: 10.17981/ladee.03.02.2022.1

Fecha de recibido 29/07/2022. Fecha de aceptado 22/09/2022.

1. Introduction

Vegetables require a lot of nutrients and intensive use of the land, a fact that requires the continuous application of NPK (nitrogen, phosphorus, and potassium) fertilizers to maintain productivity and production quality. Tomato is the most demanding vegetable in terms of fertilization and extracts about 2.8 kg to 3.7 kg of nitrogen (N) and 3.0 kg to 3.5 kg of (K_2O) per t (metric ton) of fruit produced (Gebremedhin et al., 2020). For a production of 100 tons per hectare per year, the tomato crop requires about 300 kg of N, 80 kg of P_2O_5, 450 kg of K_2O, 80 kg of SO_3, 90 kg of CaO and 50 kg of MgO per hectare per year. Evidencing the high extraction of nutrients from the soil to obtain high yields.

Tomato (*Solanum lycopersicum L.*) is the most important species, both from an economic and social point of view, due to its volume of production generated, and the generation of jobs from it. There are on average almost four million areas cultivated with the species, generating a production of about 186.8 million metric tons in 2020 (United Nations Statistics Division of the Food and Agriculture Organization-FAOSTAT, 2020). The consumption of these fruits brings several benefits to a healthy and well-balanced diet. These, in turn, are rich in minerals, vitamins, essential amino acids, sugars, and dietary fiber. These factors resulted in increased demand for tomatoes. Thus, alongside the growth in demand and the attractive price, production and the planted area have also been growing to satisfy the demand (FAOSTAT, 2020).

Due to the excessive cost of NPK fertilizers and Brazil's dependence on imports of these fertilizers, much research has been directed towards finding alternative sources of nutrients for plants. The application of rock dust is one of these alternatives, because it is a by-product of rock mining (volcanic, metamorphic, sedimentary, etc.), which can be applied in natura and, in addition to being low cost, has desirable characteristics as an agricultural input, and reduces environmental pollution (Ramos et al., 2020; Dalmora, Ramos, Plata et al., 2020; Ramos et al., 2022).

De Medeiros et al. (2021), reported positive results at field level when using doses of dacite rock powder in soybean crop, as they released macro and micronutrients into the soil. According to Ramos et al. (2020) rock dust is an agricultural input that contains essential macro and micronutrients for plants, however, its physical and chemical properties must be characterized before its application to the soil. Several research have been conducted with powder rock as an agricultural input. Burbano et al. (2022) were applied basal rock powder in quinoa culture, Ramos et al. (2021) in maize and black oat crops with dacite rock powder, and Dalmora, Ramos, Oliveira et al. (2020) were applied andesite rock as a clean source of fertilizer for eucalyptus crop.

The main step for a good production is in the association of soil conditioners, planting quality, searching for innovative technologies, conducting a balanced nutrition to meet the needs of the market and having a productive plantation, thus resulting in a plentiful and profitable harvest.

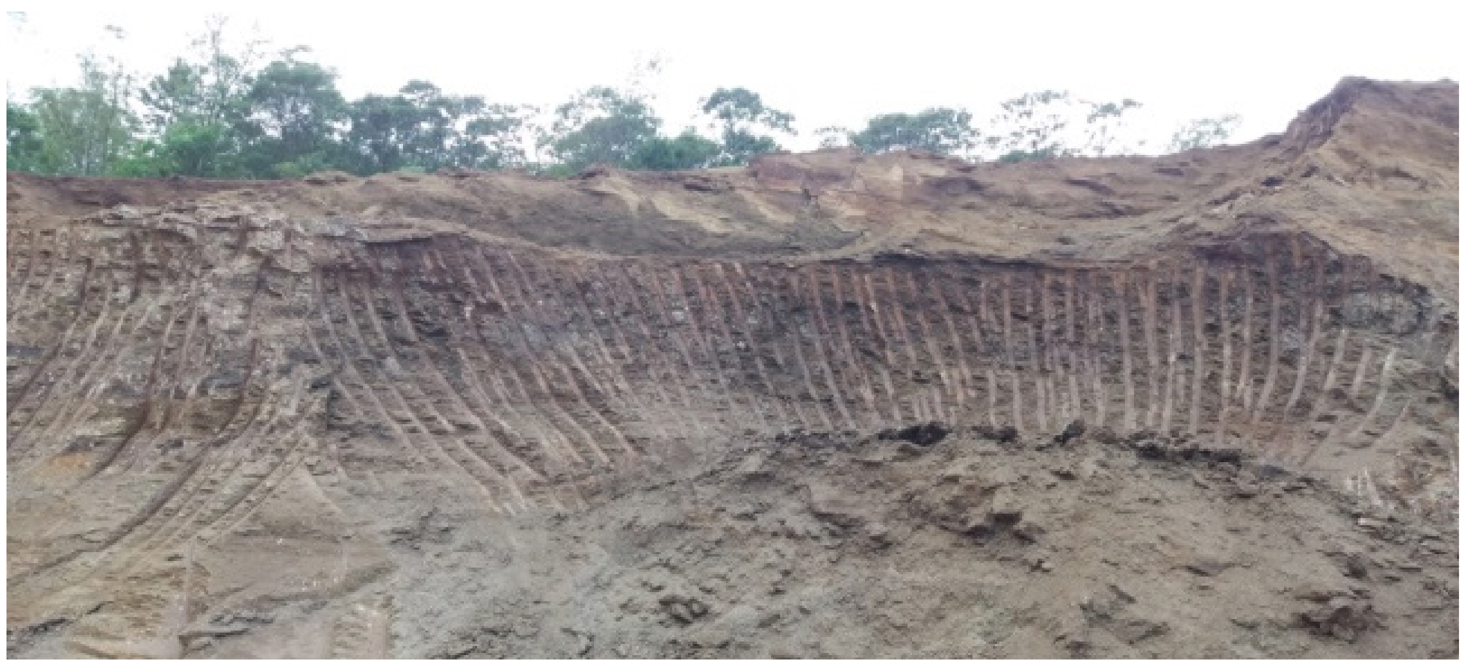
Considering the availability and geological diversity worldwide and the generation of large volumes of by-products originating from the extraction and processing of rock, it can be inferred that there is a possibility of becoming an alternative in the fertilization of vegetables, with an attractive production cost and low environmental impact.

2. Material and methods

2.1. Crushed rock

A quantity of 1 t of amygdaloid basalt rock powder with granulometry < 0.6 mm was supplied by a mining company in Santo Antônio da Patrulha city, Rio Grande do Sul, Brazil (Fig. 1).

Fig. 1. View of the amygdaloidal basalt rock miner.



Source: Photograph own authorship.

The geological environment of origin of the amygdaloidal Basalt Rock Sample (ABR) is included in the North Coast Block, according to the distribution of occurrence regions and mines from amygdaloidal basalts to zeolites proposed by Bergmann et al. (2014). The common paragenesis observed in the mining company consists of zeolites (cabazite and faujasite), smectites (montmorillonite and saponite) and plagioclase feldspar (albite). Kautzmann et al. (2020) carried out the chemical characterization of the mineral material. X-ray fluorescence (FRX) results revealed that the chemical composition in % weight of the oxides was 56.4% SiO_2, 14.6% Al_2O_3, 10.1% Fe_2O_3, 3.7% CaO, 4.04% MgO 1.12% TiO_2, 0.16% P_2O_5, 2.99% Na_2O, 2.16% K_2O, 0.16% MnO, and Loss on Ignition (LOI) of 5.2%. The multielement analysis confirmed the presence of macronutrients (1.78% of Ca, 0.15% of K, 1.86% of Mg and 586 ppm of P), in proportions like those expressed by their simple oxides in the analysis by FRX. The contents of toxic elements such as As (2 ppm), Cd (0.12 ppm), Hg (< 0.05 ppm) and Pb (8.7 ppm) show levels below the maximum values allowed by Normative Instruction (IN) No. 05/2016 of the Ministry of Agriculture, Livestock and Supply (MAPA, 2016a), for remineralizer. The presence of Cr (200 ppm) is below the maximum level of 500 ppm, allowed for agronomic substrates, according to the IN of the Secretariat of Agricultural Defense (SDA) No. 27/2006, revised in 2016 (MAPA, 2016b).

2.2. Study area

The amygdaloidal basalt rock powder application experiments for tomato cultivation were carried out in Santa Maria city, Rio Grande do Sul, Brazil, with geographic coordinates Lat: 29°38'48,371" S-Long: 53°57' 40.081" W at an altitude of 170.8 m. The experimental soil was classified as Arenic dystrophic Red Argisol, with pH: 4.7; Base saturation: 21%; Organic Matter: 1.5%; Clay: 16%; Texture: 4; K: 53.5 mg dm^{-3}; P: 10 mg dm^{-3}, Cation Exchange Capacity at pH 7.0: 9.5, at a depth of 20 cm.

2.3. Experimental design

Randomized blocks with six treatments and four replications made up the experimental design. The experimental unit consisted of plots 3 m wide and 5 m long, totaling 15 m^2 (Fig 2).

Fig. 2. General view of the experiment with tomato.

Source: Photograph own authorship.

Tomato planting was carried out with spacing of 0.25 m between plants and a sowing density of 4 plants per m^2. Treatments were applied manually on 12/30/2018, 60 days before tomato transplanting. After transplanting the seedlings, manual weeding operations were carried out on the days (02/18/2019 and 03/08/19), to eliminate weeds that occurred in the area.

Table 1 presents the treatments applied to the experimental soil.

Table 1. Description of treatments.

Treatments	Dose (kg ha^{-1})	Application Time 30 DAS[1]
1. Control	-	-
2. ABR	1.0	*
3. ABR	2.5	*
4. ABR	3.5	*
5. ABR	4.5	*
6. Standard 5-20-20	5(N)–20(P)–20(K)	*

[1] Days before sowing. Source: Own authorship.

2.4. Evaluation of agronomic efficiency

The assessment of the investigated treatments' agronomic effectiveness per experimental unit (bed) in the field consisted of the evaluations of root length, stem diameter, flowers per plant, fruits per plant, green and dry mass of shoots and roots and productivity. For evaluation, dry mass, and green mass, four plants per experimental unit were collected in preharvest, these were separated into shoots and roots and weighed to obtain the green mass.

For dry mass, they were placed in properly identified paper bags for drying in an oven with forced air circulation, at 60°C - 70°C, until they reached constant mass. The determination of green and dry mass was carried out using an electronic scale with a precision of 0.001 g.

In pre-harvest, the following parameters were also evaluated: root length (with the aid of a millimeter measuring tape), stem diameter with the aid of a digital caliper, and number of flowers and fruits per plant through manual counting.

To determine the productivity, 1 m^2 per plot of tomatoes was harvested, weighed and the productivity in kg ha^{-1} was obtained.

The gathered information was put through an analysis of variance, and averages were compared using the Scott-Knott test at a 5% significance level.

3. Results and discussions

Need for trustworthy data on how agricultural land management affects soil quality is rising. This knowledge is required to aid in the development of sustainable agricultural production methods and enhance producer economic returns (Nelson et al., 2010). Fertilizer use is crucial for boosting agricultural output, and it has significantly expanded over the past 40 years, mostly because of Brazil's widespread adoption of high-yielding, nutrient-responsive cultivars. In long-term continuous crop fields in particular, high-yield production has increased the use of NPK chemical fertilizers, resulting in macronutrient excesses but micronutrient deficits in the soil. As a result, the balance of nutrients in the soil was upset, leading to a variety of issues (Shukla et al., 2022). In the present study, a new soil amendment composed of four doses of mineral amigdaloidal basalt rock powder was applied to tomato crop to evaluate its effects as a fertilizer on plant growth properties and tomato productivity.

3.1. Green and dry mass of tomato shoots and roots

Long-term agriculture requires a balanced nutrient balance in the soil-plant systems to preserve crop yields and soil fertility (Dang, 2005). In general, when full nutrient sufficiency is offered, plants profit the most (Datnoff et al., 2006; Huber & Haneklaus, 2007). Many different types of mineral nutrients, both essential and advantageous for the growth of tomato plants, were incorporated in the soil amendment employed in the current study. Table 2 shows the averages for green and dry mass of shoots and roots, and Table 3 shows the averages for root length and stem diameter.

Table 2. Results of green mass and dry mass of shoots and roots when submitted to treatments.

Treatments	Dose (t ha^{-1})	Aerial part		Roots	
		Green mass	Dry mass	Green mass	Dry mass
		(g)			
1. Control	-	115.13b	18.157b	13.650c	1.64c
2. ABR	1.0	241.60a	29.725a	28.162a	3.44a
3. ABR	2.5	228.97a	31.109a	25.814a	2.26b
4. ABR	3.5	227.31a	25.989a	21.014b	2.59b
5. ABR	4.5	221.76a	33.873a	29.319a	3.43a
6. Standard	-	225.92a	32.767a	29.623a	3.63a
(%)		7.86	13.24	15.24	10. 84

Means not followed by the same letters in the columns differ by the Scott-Knott test at the 5% error probability level.
Source: Own authorship.

Table 3. Evaluation of root length and stem diameter of tomato plants.

Treatments	Dose (t ha^{-1})	Root length (cm)	Stem diameter (mm)
1. Control	-	19.25	6.40b
2. ABR	1.0	25.25	7.44a
3. ABR	2.5	25.00	5.95b
4. ABR	3.5	24.75	6.27b
5. ABR	4.5	26.50	5.03b
6. Standard	-	23.00	7.22a
(%)	-	Not significant	12.16

Means not followed by the same letters in the columns differ by the Scott-Knott test at 5% error probability.
Source: Own authorship.

For aerial part, both green mass and dry mass showed statistically significant difference. Treatment 2, with a dose of 1-t ha^{-1}, showed greater green mass than the control treatment and then treatments 3, 4 and 5 with a dose of 2.5, 3.5, and 4.5-t ha^{-1}, only the control treatment and treatment 5 with 4.5-t ha^{-1} were lower than the standard. For shoot dry mass, all treatments with doses of ABR powder were superior to the control, and the treatment with 4.5-t ha^{-1} was even superior to the standard.

For green and dry root mass, there was statistically significant difference between treatments. For green mass, all treatments with ABR were superior to the control, the treatment with 4.5-t ha^{-1} had practically the same mass as the standard.

The averages found for root dry mass show that all treatments were superior to the control, and the treatment with 1.0-t ha^{-1} was superior to the others, less than the standard.

According to the results of Table 3, there was no statistically significant difference between treatments, but all treatments with ABR doses were superior to the control and the standard treatment, with the treatment with 4.5-t ha^{-1} obtaining a length of 7.25 cm more compared to control and 3.5 cm larger than standard.

Observing the results for stem diameter there is a statistically significant difference between the treatments, where treatment 2, at a dose of 1.0-t ha^{-1}, showed a greater stem diameter than the other treatments. Agriculture management techniques have an impact on soil characteristics, nutrient usage effectiveness, and agricultural output. Inorganic fertilizers and agrochemicals are the mainstays of conventional crop management strategies, which have recently enhanced agricultural production (Pimentel, 2005). Yet, using too much chemical fertilizer can have a harmful impact on the environment in addition to not promoting plant growth. In addition, the use of inorganic fertilizers may hasten the breakdown of organic waste and perhaps lessen aggregate stability (Mäder et al., 2002). Farmers can utilize organic fertilizers or use less inorganic fertilizer to prevent this issue (Stockdale et al., 2000). In this investigation, some parameters associated with tomato productivity in treatment 2 had better results than the other treatments, showing that soil correction with 1-t ha^{-1} of rock dust can produce more favorable results for the plant and the soil.

Table 4 shows the results for number of flowers/plants, number of fruits/plant and productivity of the tomato crop.

For the number of flowers/plants, there was a statistically significant difference between the treatments, where all treatments with ABR doses were superior to the control treatment and to the standard treatment, and the treatment with 2.5-t ha^{-1} was superior in 156% to control treatment and 75% to standard treatment.

Table 4. Number of flowers/plants, fruits/plants and productivity of the tomato crop.

Treatments	Dose (t ha^{-1})	Number of flowers/plants	Number of fruits/plants	Productivity
			kg ha^{-1}	
1. Control	-	5.8b2	3.5	22 450b
2. ABR	1.0	12.3a	7.0	36 500a
3. ABR	2.5	14.8a	4.8	35 750a
4. ABR	3.5	14.0a	5.0	27 775b
5. ABR	4.5	12.0a	7.0	34 275a
6. Standard	-	8.5b	7.3	35 500a
(%)	-	32.64	Not significant	21.49

Means not followed by the same letters in the columns differ by the Scott-Knott test at 5% error probability.
Source: Own authorship.

Observing the averages of the treatments for the number of fruits/plants there was no statistically significant difference between the treatments, but it can be noted that all treatments with ABR were superior to the control, and the treatments at doses of 1.0 and 4.5-t ha^{-1} were 100% higher than the control.

Regarding productivity, there was a statistically significant difference between treatments, with all treatments with RBA doses being superior to the control, and even though the treatment with a dose of 1.0-t ha^{-1} reached an average productivity of 36 500 kg ha^{-1}, producing 14 050 kg ha^{-1} more than the control and 1 000 kg ha^{-1} more than the standard treatment.

The difference in productivity and fruit health can be seen in Fig. 3. In Fig. 3A was implemented the control treatment, in Fig. 3B was implemented the standard treatment, and in Fig. 3C the treatment with 1-t ha^{-1} we can notice that the tomato fruit is in a more advanced state of maturation.

Fig. 3. A) Control treatment; B) Standard treatment; C) Treatment with 1-t ha^{-1}.

Source: Own authorship.

4. Conclusions

The results of the present study showed that the use of amygdaloidal basalt powder promoted improvements in the development of the tomato crop. In the specific case of the tomato crop, it was possible to observe that the lowest applied dose of rock dust, 1.0 t ha^{-1}, showed the highest productivity of the crop. The greater demand for nutrients such as *K* required by the tomato crop may have been met effectively, as the minerals contained in the rocks (amygdaloidal basalt) may have met the need for K and resulted in better yield indicators (about 60% higher) when compared to the control treatment. Therefore, these nutrient sources indicate a potential to meet the demand for fertilizers in times of scarcity. Additionally, it is a viable, sustainable, and low-cost strategy, because they are by-products of mining companies, which contributes to the achievement of the Sustainable Development Goal (SDG 2, United Nations-UN, 2015) and can be replicated in Brazil and in the world.

Credit author statement

Adilson Celimar Dalmora, Rubens Müller Kautzmann, Jair Staub: Writing and correction**.** Ivo André Homrich Schneider: Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

We are grateful for the materials derived from amydaloid basalt rock supply by the mining company J.F.Rost Martins – EPP.

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