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## Potential of Valsungana Granite: Source of K and Sustainability in Agriculture

### *Potencial do Granito Valsungana: Fonte de K e Sustentabilidade na Agricultura*

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**Abstract:** Brazil, one of the largest food producers, imports around 93% of the potassium chloride used in agriculture. This study explores silicate rocks, specifically the Valsungana Granite (GV), from Major Gercino, Nova Trento and Brusque, SC., as an alternative source of potassium. The main objective was to evaluate the solubility of potassium through technological routes, including comminution and calcination at 710°C, with and without the addition of  $\text{CaCl}_2 \cdot \text{H}_2\text{O}$ . The samples were treated with aqueous solutions (pH 5.7 and 7.3), acids: citric, nitric and oxalic and melich-1. Potassium solubility occurred in all samples, the most effective being calcined with the addition of salt, under oxalic acid solution, followed by citric acid, melich-1, and aqueous solutions with pH 5.7 and 7.3. Potassium concentration was determined by atomic absorption. The characterization of the “in natura” granite and the calcined granite without and with the addition of flux ( $\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$ ) were carried out using X-ray diffraction and fluorescence, scanning electron microscopy and infrared spectroscopy. The results indicated ion exchange and chemical reactions, demonstrating the potential of GV as a source of potassium fertilizer and suggesting the need for further studies on the availability of K in the soil.

**Keywords:** Potassium; Sustainable agriculture; Valsungana Granite.

**Resumo:** O Brasil, um dos maiores produtores de alimentos, importa cerca de 93% do cloreto de potássio usado na agricultura. Este estudo explora as rochas silicáticas, especificamente o Granito Valsungana (GV), proveniente de Major Gercino, Nova Trento e Brusque, SC., como fonte alternativa de potássio. O objetivo principal foi avaliar a solubilidade do potássio através de rotas tecnológicas, incluindo cominuição e calcinação a 710°C, com e sem adição de  $\text{CaCl}_2 \cdot \text{H}_2\text{O}$ . As amostras foram tratadas com soluções aquosas (pH 5,7 e 7,3), ácidos: cítrico, nítrico e oxálico e melich-1. A solubilidade do potássio ocorreu em todas as amostras, sendo a mais efetiva, calcinada com adição do sal, sob a solução do ácido oxálico, seguido do ácido cítrico, melich-1, e soluções aquosas com pH 5,7 e 7,3. A concentração de potássio foi determinada por absorção atômica. A caracterização do granito “in natura” e do calcinado sem e com adição de fundente ( $\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$ ), foram realizadas por difração e fluorescência de raio-X, microscopia eletrônica de varredura e espectroscopia de infravermelho. Os resultados indicaram troca iônica e reações químicas, demonstrando o potencial do GV como fonte de fertilizante de potássio e sugerindo a necessidade de estudos adicionais sobre a disponibilidade de K no solo.

**Palavras-chave:** Potássio; Agricultura sustentável; Granito Valsungana.

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## 1. Introduction

The UN (United Nations Organisation, 2022) predicts that the world's population could reach 9 billion people by 2050. In this context, the FAO (2017) states that food production must grow by fifty percent to meet demand. Population growth presupposes intensive exploitation of the natural resources in order to increase the supply of food, with the aim of promoting health and quality of life.

Brazil has the potential to lead almost half of the world's food production, which would significantly increase the demand for inputs (MAPA, 2022). Therefore, sustainable agricultural practices and mitigation measures are essential to conserve soil and water quality (WEINZETTEL et al. 2013).

Fertiliser prices have reached an all-time high since the beginning of the Russia-Ukraine conflict, and may remain high for quite some time (SEIXAS, 2022). The increase in the cost of these essential elements adversely affects the exports of the Brazilian agricultural sector, reducing the competitiveness of the national product, since a large part of the production cost is the cost of imported fertiliser.

Rock-cutting has emerged as an excellent sustainable alternative to conventional agricultural fertilisers, since Brazil has exceptional geodiversity and is able to provide different types of rocks with different characteristics in various parts of the country (BRITO et al. 2019).

Remineralisers rejuvenate impoverished or degraded soils, acting as a reservoir of low-solubility nutrients, which it makes available to the plant during its development (THEODORO, et al. 2010).

Rock cutting, identified as an innovative technology, aims to reduce the excessive use of chemical inputs, acting as a complementary method for restoring or remineralising the soil (VAN STRAATEN, 2002). This approach replaces chemical fertilisers, which are known for their negative effects on the environment. Thus, Rock dust cutting is a mineral fertiliser that is economic to use and reduces the environmental impacts (PEREIRA et al. 2015).

Rock dust facilitates soil remineralisation due to its rich mineral content and chemical composition, making it suitable for improving soils with limited fertility or for recovering soils impoverished by leaching (ALOVISI et al. 2020).

The rock-cutting process increases soil fertility, reduces production costs and generates more sustainable effects compared to chemical fertilisers, slowly releasing a range of essential nutrients for the soil and plants (e.g. K, P, Fe, Mn, Zn, Cu) (AQUINO et al. 2020), as well as various trace elements, which contribute to improving water retention in coarser-textured soils (BEERLING et al. 2018).

The agronomic efficacy of silicate rock powders depends on the geochemistry, mineralogy and granulometry of the ground rock, and on soil and climate conditions (MARTINS et al. 2014).

The main challenge associated with the release of potassium from potassic aluminium silicates lies in the fact that the potassium ion is strongly incorporated into the aluminium-oxygen-silicon (Al-O-Si) structure, leading to low solubility of potassium in non-aggressive aqueous solutions.

To optimize the extraction of potassium from insoluble sources, various methods have been explored, mainly focusing on thermal and chemical treatments (HASELI et al. 2019). The general objective of this study was to evaluate the solubilisation of potassium ions through the rock "in natura", calcined at 710°C, without and with the addition of  $\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$ , the chemical and mineralogical characteristics of the samples used in the different technological methods, and the environmental advantages of using Valsungana Granite in agriculture.

## 2. Methodology

A total of 100 kg of sample was collected at the Nova Descoberta mine, in the municipality of Major Gercino/SC, Brazil, from different points along the mining front. This sample is part of the Valsungana Suite and is identified as syenogranite. The 100 kg sample of ore was homogenised, quartered and a 15 kg fraction was dried at 65 °C, crushed, ground, homogenised and quartered again.

It was sieved in a shaker for ten minutes at 10 Hz until it passed through a 30 sieve (MESH TYLER) with an opening of 0.6 mm. According to Yuan et al., (2015), the K extraction rate is linked to temperature, time, ore rate and ore particle size.

Eight thin slides were prepared for petrographic analysis, five of the rock and three of the ore, called GVin (granite in natura), GVc (calcined granite) and GVcc (calcined granite with the addition of  $\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$ ).

The GVin, GVc and GVcc samples were ground, homogenised with wax and boric acid to form the base of the tablets, and analysed in an X-ray fluorescence spectrometer (XRF), with data processed in Super Q Manager software.

The diffractometric analyses used a SIEMENS-BRUKER-AXS D5000 diffractometer with  $\theta$ - $\theta$  goniometer and  $K\alpha$  radiation in a coppertube (40 kV, 25 mA), scanning from  $2^\circ$  to  $72^\circ$   $2\theta$ , and speed 2 seconds per  $0.02^\circ$ .

The crystalline phases were identified using the RIETVELD method. For SEM/EDS, sample fragments were prepared on copper stubs and coated with silver.

Microscopic analyses were carried out using a Hitachi/TM 3000 scanning electron microscope and a Brucker/Quantax 70 microprobe, both operating with backscattered electrons (BSE) at an accelerating voltage of 15 kV. Fourier transform infrared spectroscopy (FT-IR) analyses were carried out using the DRIFTS method, covering a spectrum from 400 to 4000  $\text{cm}^{-1}$ , using SHIMADZU IRPrestige-21 equipment, with samples mixed in KBr(s).

Potassium solubility was assessed in the laboratory, with the samples subjected to calcination at  $710^\circ\text{C}$  for 60 minutes, followed by rapid cooling. This process was carried out on both pure samples and samples with added  $\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$ .

The following steps were followed to prepare the solutions: I) Weighing 0.01 kg of the sample and adding 50 ml of extractant solution to a snap cap; II) Placing the snap caps on a shaking table at 120 rpm at  $25^\circ\text{C}$ ; III) Shaking for varying periods of 10 to 600 minutes; IV) Use of different extractants, including water with pH 5.7 and 7.3, citric, nitric, oxalic acids at 0.02 mol/L and Melich-1; V) Resting the samples for 18 hours for decantation; VI) The analyses involved 4 replicates, 15 times, 6 extractants and 1 chemical element, and the results were statistically analysed using the Kruskal-Wallis test.

### 3. Results and discussions

#### 3.1 Granulometry

The grain size of the ore varied, with different fractions: coarse sand (2.15%), medium sand (31.08%), fine sand (22.26%), very fine sand (15.85%), silt (11.99%) and clay (16.68%). The smaller the particle size, the greater the release of minerals (LUZ et al. 2010). This variation increases the surface area, influencing dissolution, nutrient release, energy heterogeneity and adsorbed ion concentrations, affecting chemical interactions with the soil.

#### 3.2 Petrographic and genetic characterisation

The Valsungana Granite (GV) has an inequigranular, holocrystalline and porphyritic texture, with phenocrysts of up to 7 cm in medium matrix. Composed mainly of alkali feldspar (25%-60%), plagioclase (20%-30%), quartz (18%-35%) and biotite (0-8%), it includes accessories such as allanite, titanite, apatite and zircon, and secondaries such as muscovite, epidote and chlorite, according to petrographic analyses of samples from Major Gercino. Figure 1A shows quartz with undulating extinction and lobulated edge, sericitised plagioclase and reddish brown biotite. In 1B, biotite shows a “king bands” texture. In 1C, feldspar-K perthite with quartz in microfractures. Figure 1D shows altered feldspar with clay minerals and brown biotite. Figure 1E shows maculated K-feldspar and plagioclase. According to Caldasso et al. (1995), the GV has a unique genetic origin, with variations linked to magmatic evolution and differentiation in a magma chamber, typifying it as an ‘S’ type granitoid. The conditions under which the GV was formed, including thermal and tectonic conditions, caused deformations and structural defects, making it more reactive to soil acids and unique among the granites of Santa Catarina.

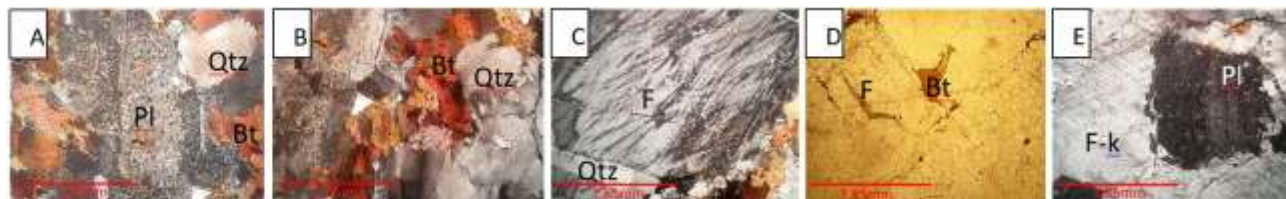


Figure 1 – Magnification 25X: 1A) Quartz with undulating extinction; sericitised plagioclase; reddish biotite. 1B) Biotite with “king bands” texture. 1C) Perthitic K-feldspar; recrystallised quartz in microfractures. 1D) Feldspar altered with clay minerals; brown biotite. 1E) K-feldspar and maculate plagioclase.

Source: Authors (2024)

### 3.3 Optical microscopy of the granulated ore

Figure 2A shows GVin with minerals such as plagioclase and biotite. It shows granulometric variation, F-K (microcline, with perthite), biotite (Bt) and quartz (Qtz). In figure 2B, after calcination at 710°C, there are structural changes in the biotite and optical changes in the plagioclase and quartz (Qtz) with a reactive edge (yellow arrow), plagioclase grains (Pl) in an advanced stage of seritisation, biotite (Bt) in an advanced stage of alteration due to iron oxidation caused by calcination. Figure 2C, with  $\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$  added post-calcination, shows the formation of new minerals, such as calcium silicates, indicating mineral transformations and recrystallisation in GVin, due to calcination with the addition of  $\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$ .

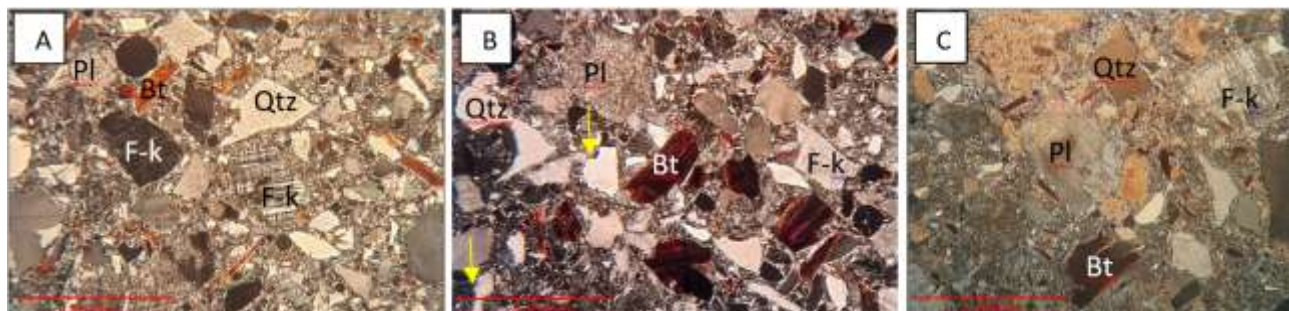


Figure 2 – 25x magnification. Microphotograph of the minerals of the Valsungana Granite (GV) in the samples: A) GVin, B) GVc and C) GVcc

Source: Authors (2024)

### 3.4 Chemical analysis (FRX)

In the calcination test, the ion exchange was insignificant (Table 1). The main oxides were  $\text{Na}_2\text{O}$ ,  $\text{MgO}$ ,  $\text{K}_2\text{O}$  and  $\text{CaO}$ , with mass gains of 0.0209%, 0.085%, 0.0387% and 0.0862%, respectively. The change in mass was insignificant because under these conditions, there was no dehydroxylation of the feldspars, and the chemical compositions remained similar because this rock contains a low percentage of volatile elements. Under the same temperature conditions, however, the addition of salt as an input species caused an imbalance in the chemical reactions. The leaching rates were higher for  $\text{Na}_2\text{O}$  and  $\text{K}_2\text{O}$  due to their chemical affinity with chloride. The leaching rate of alumina, which was 0.35%, indicates that the Al-O-Si structure had been broken and partially leached.

*Table 1 – Main oxides of GVin, GVc and GVcc, in percentages*  
**VALUES EXPRESSED AS % OF OXIDES, STANDARDISED TO 100%**

Element / Oxide	SAMPLES		
	<i>GVin</i>	<i>GVc</i>	<i>GVcc</i>
<b>Na<sub>2</sub>O</b>	1.40	1.43	1.17
<b>MgO</b>	0.43	0.47	0.55
<b>Al<sub>2</sub>O<sub>3</sub></b>	16.74	16.73	16.80
<b>SiO<sub>2</sub></b>	69.18	69.26	62.08
<b>P<sub>2</sub>O<sub>5</sub></b>	0.00	0.00	0.00
<b>SO<sub>3</sub></b>	0.01	0.01	0.01
<b>Cl</b>	0.01	0.01	1.74
<b>K<sub>2</sub>O</b>	8.68	9.03	8.62
<b>CaO</b>	0.53	0.58	2.92
<b>TiO<sub>2</sub></b>	0.22	0.24	0.22
<b>Cr<sub>2</sub>O<sub>3</sub></b>	0.03	0.02	0.03
<b>MnO</b>	0.03	0.02	0.02
<b>Fe<sub>2</sub>O<sub>3</sub></b>	1.79	1.91	1.86
<b>PF *</b>	1.49	2,00	4,60

*Source: Authors (2024)*

### 3.5 X-ray diffractometry (XRD)

X-ray diffractometry (Figure 3) showed compositional changes in the Valsungana Granite after calcination GVc and treatment with CaCl<sub>2</sub>.2H<sub>2</sub>O GVcc, compared to *in natura* GVin. GVc showed an increase in quartz to 16.59%, and a reduction to 10.79% in GVcc, suggesting the influence of CaCl<sub>2</sub>.2H<sub>2</sub>O on solubility. Microcline decreased to 44.1% in GVcc, indicating structural changes due to chemical action. Albite increased to 24.77% in GVcc, possibly due to the stability or decomposition of volatiles. Kaolinite decreased to 8.85% in GVcc, reflecting dehydration and structural changes. Illite increased to 12.75% in GVc and decreased to 11.5% in GV cc, (Table 2) indicating variations in crystallinity by CaCl<sub>2</sub>.2H<sub>2</sub>O. These results are in line with the findings of Yuan et al. (2015) and Haseli et al. (2019), who studied mineral variations in similar contexts.

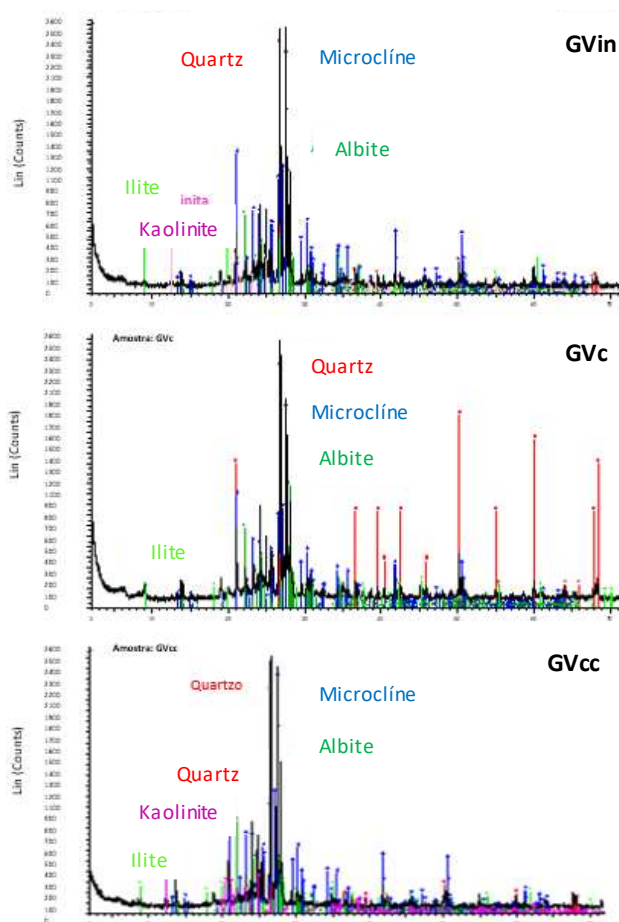


Figure 3 – Diffractograms of samples A) GVin, B) GVc and C) GVcc.  
Source: Authors (2024)

Table 2 – Identification of the phases and quantification in % of GVin, GVc and GVcc.

Identified phase (%)	Quantification (%)		
	GVin	GVc	GVcc
Quartz	14.49	16.59	10.79
Microcline	47.30	46.74	44.10
Albite	21.05	23.92	24.77
Kaolinite	9.17	-	8.85
Illite	9.59	12.75	11.50

Source: Authors (2024)

### 3.6 Scanning electron microscopy (SEM)

The results of the electron microscopy, figure 4, show cleavage in GVin, indicated by the blue arrow, as well as the presence of microfractures, indicated by the red arrow in the upper part of the image. In contrast, the GVc sample, illustrated in figure 4B, shows more obvious and open cleavages, due to plate detachment along the cleavage planes, an effect resulting from abrupt cooling. The red arrow highlights a sintered texture in the agglomeration of mineral grains, a consequence of heat treatment at 710 °C. This phenomenon is attributed to the shrinkage and relaxation of the minerals due to the abrupt change in temperature during treatment. Finally, sample GV cc, figure 4C, shows a cluster of minerals



that were calcined at 710 °C in the presence of  $\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$ . The texture of the agglomerate, described as saccharoidal, suggests a crystalline rearrangement resulting from the thermal process and subsequent chemical interaction.

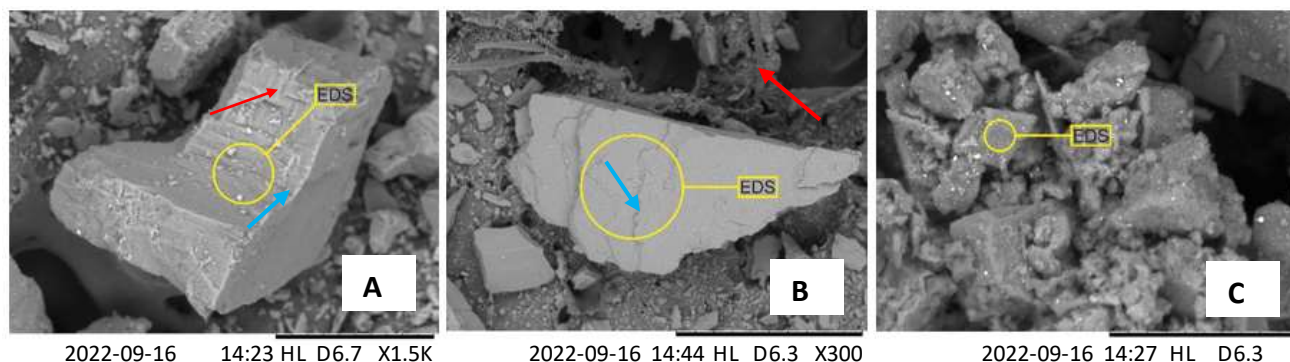


Figure 4 – Micrographic identification of K-feldspar: A) GV<sub>in</sub> cleavage (blue arrow); B) GV<sub>c</sub> cleavage opening (blue arrows) and partial gluing of the minerals (red arrow); C) GV<sub>cc</sub> ore fusion process.

Source: Authors (2024)

The micrograph, figure 5A, illustrates the GV<sub>in</sub> sample with irregular porosity before calcination. In contrast, figure 5B, representing GV<sub>c</sub>, shows enlarged pores after heat treatment. Figure 5C, on the other hand, shows an increase in the number of pores, now infused with  $\text{CaCl}_2$  and/or  $\text{NaCl}$ , while figure 5D highlights pores of increased size and uneven distribution. These observations show the morphological changes resulting from calcination with and without the addition of salts.

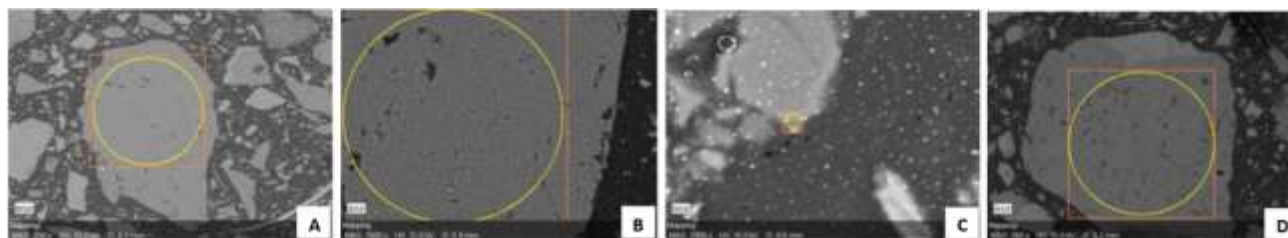


Figure 5: Figures 5A, 5B, 5C and 5D represent the areas where the quartz was analysed by EDS.

Source: authors (2024)

### 3.7 Feldspar-K and Quartz Chemistry - EDS Analyses

Table 3 shows the chemical composition of the GV<sub>in</sub>, GV<sub>c</sub> and GV<sub>cc</sub> samples. In GV<sub>in</sub>, the main elements are potassium (K) and oxygen (O), accounting for over 67 per cent of the composition. Traces of aluminium (Al), sodium (Na), iron (Fe) and manganese (Mn) are also detected. In GV<sub>c</sub>, there are significant changes, such as an increase in oxygen (O) and a decrease in potassium (K), with an increase in sodium (Na) and the presence of calcium (Ca) and, in GV<sub>c</sub>, an increase in sodium (Na) levels and the detection of chlorine (Cl) in the composition stand out. Suggesting chemical interactions induced by the treatments.

Table 3 – Chemical composition of K-feldspar by EDS method

Chemical elements (wt%)	GVin	GVe	GVcc
Si	38.64	38.68	38.41
O	28.65	31.58	32.68
K	19.84	16.04	10.97
Al	11.69	11.70	12.23
Na	0.47	1.50	3.77
Fe	0.28	0.26	0.19
Mn	0.24	n.d	0.07
Ca	n.d	0.24	0.99
Cl	n.d	n.d	0.69

Source: Authors (2024)

According to Table 4, the GVin sample shows the primary composition of quartz, dominated by silica (Si) and oxygen (O), with 55.22% and 43.30% respectively, as well as traces of potassium (K) 1.14%, iron (Fe) 0.24%, calcium (Ca) 0.09%, magnesium (Mg) 0.01% and aluminium (Al) 0.01%. The GV(c) sample, after calcination at 710°C, shows compositional changes: Si decreases to 47.77%, while O increases to 50.98%, with a reduction in the K, Fe, Ca, Mg and Al contents compared to GVin. Analysis of GVcc(b), corresponding to the edge of the mineral, shows higher concentrations of K (1.22%), Fe (0.03%), Ca (2.08%), Al (2.46%) and sodium (Na) (0.10%) than GVcc, indicating a heterogeneous distribution of elements, which is more concentrated at the edge of the quartz.

Table 4 – Variations in chemical composition.

		GVin	GVe	GVcc(b)	GVcc
Element	Série	Atom.C(at.%)	Atom.C(at.%)	Atom.C(at.%)	Atom.C(at.%)
Silica	K-Séries	55.22	47.77	42.59	49.97
Oxygen	K-Séries	43.30	50.98	49.14	48.57
Potassium	K-Séries	1.14	0.74	1.22	0.08
Iron	K-Séries	0.24	0.13	0.00	0.03
Calcium	K-Séries	0.09	0.25	2.08	0.34
Aluminum	K-Séries	0.01	0.04	2.46	0.28
Sodium	K-Séries	0.00	0.00	0.00	0.10
Magnesium	K-Séries	0.01	0.09	-	-
Chlorine	K-Séries	-	-	2.51	0.62
Manganese	K-Séries	-	-	0.00	0.00
Total		100.00	100.00	100.00	100.00

Source: Authors (2024)

### 3.8 Fourier transform infrared spectroscopy (FT-IR)

Infrared spectroscopy analysis was carried out to investigate the suspected potential changes in GV resulting from the calcination process with and without salt, as shown in Figure 6.



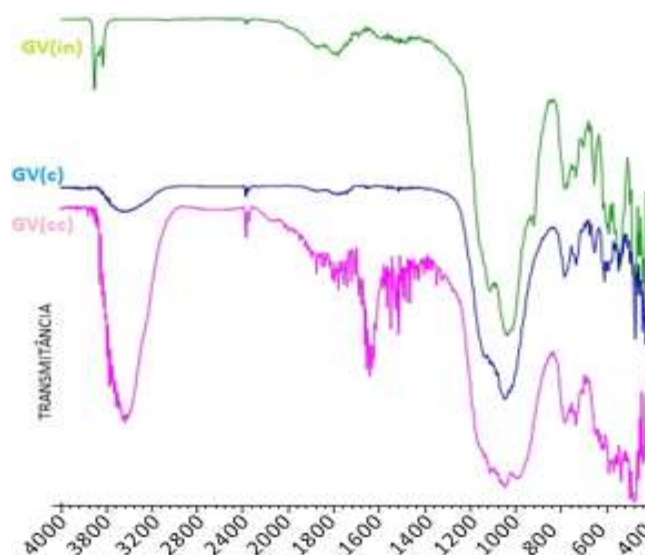


Figure 6 – Infrared spectra of the samples - GV(in) (green), GV(c) (blue) and GV(cc) (lilac).  
Source: Authors (2024)

The infrared spectrum of untreated GV(in) granite shows a stable baseline, demonstrating that the sample has not undergone any previous alterations. The high transmittance observed is characteristic of quartz, especially in the broad infrared transmission range, which generally includes the region between 4000 and 400  $\text{cm}^{-1}$ . The absorption band at 3400  $\text{cm}^{-1}$ , present in the GV(in) spectrum, is generally associated with water or hydroxyl groups within the mineral structure. Calcination at 710°C in GV(c) resulted in dehydration and structural transformations; the changes in the absorption peaks at between 1000 and 1100  $\text{cm}^{-1}$  in the GV(c) spectrum may indicate the reorganisation of the silicates or the crystallisation of new mineral phases due to changes in the crystallinity conditions of the sample's constituents after calcination. In the GV(cc) sample, the chemical reactions suspected of occurring in the sample, due to calcination and treatment, were evidenced by the presence of the broad band near the 3400  $\text{cm}^{-1}$  region attributed to the  $\text{OH}^-$  stretching in  $\text{Ca}(\text{OH})_2$  and  $\text{H}_2\text{O}$ , respectively, common in minerals containing water or hydroxyl groups. Furthermore, in the 1800 to 1340  $\text{cm}^{-1}$  range, the presence of multiple bands contrasts with the singularity that is commonly expected, which may indicate the existence of various types of chloride bonds and complex interactions with the water mol.

### 3.9 Potassium solubility

Tables 5A, 5B and 5C show the solubility of potassium in all the extractant solutions tested, corresponding to the GV(in), GV(c) and GV(cc) samples, respectively. The Kruskal-Wallis test rejected the null hypothesis of equal medians between the groups ( $p = 5.646e-46$ ), indicating statistically significant differences. Organic acids (oxalic and citric) were more effective in extracting potassium because, in addition to their pKa values (1.25 and 3.13) respectively, they had greater dissociation capacity, factors such as acidolysis and complexation, which are associated with the extraction process (MATSUYA & MATSUYA, 1994). The results indicate that extraction with oxalic acid was more effective, with concentrations ranging from 320 to 334.5 mg/kg. These data suggest that oxalic acid is a more efficient potassium (K) extractant. It was observed that citric acid showed a significant improvement in solubilisation efficiency after the structural modification process, showing the positive influence of structural changes on the extraction capacity of this acid. When using water with a pH of 5.7, the solubility of potassium showed notable variations, ranging from 22 mg/kg in the GV(in) sample to 121 mg/kg in the GV(cc) sample. On the other hand, when using water with a pH of 7.3, it was observed that this was the extractant with the lowest solubilisation capacity, with concentrations ranging from 13.5 mg/kg in the GV(in) sample to 52.5 mg/kg in the GV(cc) sample. This difference in solubilisation capacity can be attributed to the concentration levels of  $\text{H}^+$  ions in the water. Water with a pH of 5.7 has a higher concentration of  $\text{H}^+$  ions, facilitating more efficient ion exchange compared to water with a pH of 7.3. When extracted with melich-1 solution, GVCC showed lower potassium solubility values (50mg/Kg) compared to the GV(in) and GV(c) samples (73 and 62mg/Kg, respectively). These values are related to the exchangeable cations adsorbed on the grain surfaces. Nitric acid was not as

effective as the other solutions, due to the variation in the size of the grain size ranges used in the study, which interfered with the extraction process, hindering the internal reactions between the minerals and the acid solution. The water extractant (pH 5.7) has low dissociation potential compared to the other extractants used in this research; however, it was more effective at solubilising potassium than citric acid, which has an acid dissociation constant (pKa) of -1.4. Santos et al. (2015) assessed the chemical dissolution of verdigris after heat treatment using increasing amounts of acids or bases at different temperatures and reaction times. LiCl, CaCl<sub>2</sub>·2H<sub>2</sub>O, Na<sub>2</sub>CO<sub>3</sub> and NaCl were used as fluxing agents. The CaSO<sub>4</sub>, CaCO<sub>3</sub> and Ca<sub>3</sub>(PO<sub>4</sub>)<sub>2</sub> salts were ineffective. In addition, according to the authors, dissolving potassium with NaOH was more efficient than with acids, and it was possible to solubilise up to 60% of K from verdigris with 4.0 mol/L of NaOH at 150°C for 120 minutes. H<sub>3</sub>PO<sub>4</sub> acid was the most efficient, solubilising up to 42% of the potassium with 4.0 mol/L of H<sub>3</sub>PO<sub>4</sub> at 225°C for 120 minutes. Yunan et al. (2015) studied the extraction of potassium from feldspar through calcination, using hydrated calcium chloride as a flux. The conversion reaction began at approximately 600°C and accelerated with increasing temperature. As the temperature rose above 900°C, the extraction of potassium gradually decreased due to the volatilisation of the product, KCl. Around 41% of the potassium was volatilised in 40 min at 1100°C. The mass ratio of CaCl<sub>2</sub> /feldspar-K ore significantly affected extraction.

*Table 5A – K solubility in mg/L with different stirring times and extractants in the GVin sample.*

Time (min)	GVin H <sub>2</sub> O (pH5.7)	GVin H <sub>2</sub> O (pH7.3)	GVin Citric Acid	GVin Mehlich-1	GVin Nitric Acid	GVin Oxalic Acid
10	20.0	17.5	73.0	62.0	37.5	264.0
20	26.5	9.5	76.0	61.5	39.7	325.5
30	21.0	11.5	78.0	62.0	38.3	326.5
40	20.0	11.0	74.5	61.5	38.9	325.5
50	19.5	11.0	79.0	61.5	37.7	320.0
60	19.5	10.0	76.0	61.5	37.8	325.0
120	22.0	16.0	83.0	61.5	39.8	325.0
180	22.0	12.5	84.0	73.5	39.3	320.5
240	22.0	13.5	84.0	73.5	37.7	319.5
300	23.5	20.0	86.0	73.5	39.4	318.5
360	21.0	13.5	84.5	73.0	38.0	301.5
420	24.5	12.5	90.5	73.0	38.2	307.5
480	24.5	38.5	94.0	73.0	37.6	320
540	24.0	18.5	96.0	73.0	40.0	305.5
600	26.5	21.5	97.5	73.0	39.5	320

*Source: Authors (2024)*

*Table 5B – K solubility in mg/L with different stirring times and extractants in the GVc sample.*

time(min)	GVc H <sub>2</sub> O (pH5.7)	GVc H <sub>2</sub> O (pH7.3)	GVc Citric Acid	GVc Mehlich-1	GVc Nitric Acid	GVc Oxalic Acid
10	33.5	19.5	62.0	61.5	31.0	320.5
20	38.0	16.5	75.0	61.0	35.3	321.5
30	43.5	17.5	73.0	61.5	36.0	321.5
40	38.0	17.5	72.0	61	37.5	323.5
50	40.5	18.0	77.0	61.5	36.0	324.5
60	41.0	20.5	79.5	61.5	33.8	324.0
120	48.5	33.5	93.5	62.0	36.2	323.5
180	36.5	29.5	87.0	65.5	37.1	323.0
240	38.0	23.5	79.0	65.0	37.6	324.0

300	51.5	26.5	95.5	65.0	37.3	324.0
360	61.0	30.0	98.5	65.0	37.8	323.5
420	41.0	24.5	89.5	65.0	39.0	323.0
480	43.0	25.0	90.0	65.0	37.2	324.0
540	49.5	24.5	91.0	62.5	37.7	323.5
600	46.5	25	95.8	60.0	39.2	323

Source: Authors (2024)

Table 5C – K solubility in mg/L with different stirring times and extractants in the GVcc sample.

Time(min)	GVcc H2O (pH5.7)	GVcc H2O (pH7.3)	GVcc Citric Acid	GVcc Mehlich-1	GVcc Nitric Acid	GVcc Oxalic Acid
10	120.5	53	84	49.5	40.3	334
20	120.5	52	90	49.5	40.5	334.5
30	212	52	89	51	37.6	335
40	121	52	100	49.5	39.4	327
50	120.5	53	102	65.6	38.7	334
60	120	53.5	102	49.5	38.2	334.5
120	120	52.5	103	65.5	40.4	326.5
180	121	53	123	50.5	38.5	340.5
240	121	53	111	50	38.5	430.5
300	121	52	117	50	38.5	433
360	121	53.5	125	50	38.3	328
420	120	51.5	130	50	38.4	309.5
480	121	52.5	129	50	38.2	327.5
540	121	52.5	132	50	38.8	338.5
600	120.5	51.5	125	50	38	359.5

Source: Authors (2024)

### 3.10 Environmental advantages of using Valsungana Granite in agriculture

Remineralisers, such as the Valsungana Granite, provide significant environmental benefits in agriculture. These minerals enrich the soil with macro and micronutrients, increasing its fertility and improving its structure, as demonstrated by Leonardos et al. (1976). Research into solubility, emphasised by Van Straaten (2010), reveals the effectiveness of these minerals in releasing indispensable cations into the soil. The use of granite promotes soil revitalisation, contributing to the growth of healthy plants free from nutritional deficiencies and trace element toxicity, as reported by Barral et al. (2013). In addition, the use of remineralisers such as granite favours carbon sequestration, mitigating climate change. This practice is in line with the UN Sustainable Development Goals (2015), particularly with regard to the protection of terrestrial life and the fight against global climate change. From an ecological point of view, granite, when used in agricultural practices and environmental restoration projects, supports biodiversity and strengthens the sustainability of ecosystems, emphasising the great importance of these minerals in promoting a more sustainable and green agricultural future.

### 4. Final Considerations

The study showed ways of mobilizing, extracting and obtaining K for various purposes, including agricultural purposes, considering different calcination conditions and the addition of CaCl<sub>2</sub>.H<sub>2</sub>O. GV proved to be a promising source of potassium, an essential nutrient for plant growth. Calcination at 710°C, both with and without the addition of CaCl<sub>2</sub>.H<sub>2</sub>O, as it released potassium from the rocks, making it a potential source of this nutrient for agriculture. Calcination at 710°C had a significant impact on modifying the characteristics of the GV samples, affecting the crystalline structure of the minerals present in the rocks. The addition of CaCl<sub>2</sub>.H<sub>2</sub>O during calcination resulted in

chemical interactions that affected the sodium and chlorine contents in the samples. The particle size analysis revealed variations in the distribution of particle sizes in the samples, capable of influencing the dissolution and release of nutrients in the soil. The use of GV as a source of potassium in agriculture could be a sustainable alternative to traditional chemical fertilisers, helping to reduce production costs, improve soil fertility and reduce environmental impacts. The results of this study highlight the potential of Valsungana Granite as a source of potassium in agriculture, especially after calcination. However, further research is needed to fully understand the mechanisms involved in potassium release, and how these rocks can be better utilised in agriculture in a sustainable way. This approach can contribute to reducing agricultural production costs and preserving natural resources, while meeting the demands of increasing food production for the world's growing population. In order to prove the results obtained in the laboratory, it is essential to carry out agronomic efficiency studies in the greenhouse and in the field, to validate the applicability and effectiveness of the Valsungana Granite as a remineraliser in the real agricultural environment.

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