**BIODIVERSITAS**
Volume 23, Number 12, December 2022
Pages: 6579-6586

ISSN: 1412-033X
E-ISSN: 2085-4722
DOI: 10.13057/biodiv/d231257

# The ability of potassium-solubilizing fungi isolated from leucite potassium rock deposits

**ANDI RAHAYU ANWAR[1,♥], AMBO ALA[2], TUTIK KUSWINANTI[3], ELKAWAKIB SYAM'UN[2]**
[1]Doctoral Program in Agricultural Science, Graduate School, Universitas Hasanuddin. Jl. Perintis Kemerdekaan Km 10, Makassar 90245, South Sulawesi, Indonesia. Tel./Fax.: +62-411-586200, ♥email: rahayuanwar7@gmail.com
[2]Department of Agronomy, Faculty of Agriculture, Universitas Hasanuddin. Jl. Perintis Kemerdekaan Km 10, Makassar 90245, South Sulawesi, Indonesia
[3]Department of Plant Pest and Disease, Faculty of Agriculture, Universitas Hasanuddin. Jl. Perintis Kemerdekaan Km 10, Makassar 90245, South Sulawesi, Indonesia

Manuscript received: 17 September 2022. Revision accepted: 17 December 2022.

**Abstract.** *Anwar AR, Ala A, Kuswinanti T, Syam'un E. 2022. The ability of potassium-solubilizing fungi isolated from leucite potassium rock deposits. Biodiversitas 23: 6579-6586.* Present investigation was aimed to explore the potassium-dissolving ability of some indigenous fungi living in Indonesian leucite tuffs from volcanic rock members of Camba Formation in Barru Regency, South Sulawesi Province. There are no such findings on potassium-solubilizing fungi from South Sulawesi Province. The recent study isolated some fungi strains from the rhizosphere of vegetation found in the potassium rock deposits using Alexandrov media. A total of 22 fungal strains were isolated and tested for their ability to dissolve potassium bound to the potassium carrier minerals, qualitatively and quantitatively. Production of indole-3-acetic acid (IAA) and gibberellic acid (GA3) were also measured to test the ability of the fungus to produce growth regulator compounds. Fungal isolates with the highest dissolution index (IP) values were MgT1Pb, RgGc, PT3Pe, PT3Pa, JbT2Pa, JbT2Pd, and JbT2Pp. The highest amount of exchangeable potassium (K-exch.) was JbT2Pa with the amount of 919.8 ppm and MgT1Pb of 69.33 ppm. The isolate capable of producing the highest IAA was PsT2Pe at 6.820 ppm while the RgGd isolates resulted in the highest production of GA3 hormone at 4.116 ppm.

**Keywords:** Gibberellic acid, indole acetic acid, insoluble K, potassium-solubilizing fungi, rock deposits, solubilization

## INTRODUCTION

Potassium is one of the macronutrients needed by plants. Potassium plays an important role in plant growth and development having function in activating enzymes, maintaining cell turgor, increasing photosynthesis, reducing respiration, assisting in the transport of sugars and starches, and also assisting in nitrogen absorption. It is also a very important nutrient for protein synthesis. In addition to plant metabolism, potassium improves crop quality as it aids grain filling, hence kernel weight, strengthens hay, increases disease resistance, and helps plants to better withstand the stress (Meena et al. 2016). Potassium deficiency in plants will inhibit root growth, cause stunted plants, imperfect fruit growth and in turn, decrease plant production (Dasan 2012; Wang and Wu 2013; Sembiring and Sabrina 2022). Potassium in the soil available to be absorbed by plants is only around 2-10%, on the other hand, about 90 to 98% of the total potassium is in a form that is not available for plants (Pratama et al. 2016). The form of potassium in the soil is determined by some soil physical and chemical condition including soil pH, texture, type and mineral content of clay, water content, soil cation exchange capacity (CEC), and interactions with other cations such as Ca and Mg (Sembiring and Sabrina 2022). Low content of potassium in its available form in the soil causes low absorption of potassium by plants which in turn will result in poor plant growth and quality. This emphasizes the search to find alternative and effective native potassium sources for plant uptake and also to maintain adequate potassium status for crop growth and production (Meena et al. 2015).

Indonesia has a potential source of potassium. Among common potassium-carrying minerals are K feldspar ($KAlSi_3O_8$), leucite ($KAlSi_2O_6$), and trachyte (Setiawati and Mutmainnah 2016). Barru Regency in South Sulawesi Province has mineral deposits containing potassium which can be used as a source of raw material for potassium fertilizer. These rocks are leucite tuff from volcanic rock members of the Camba Formation which are scattered in the Tanete Rilau District such as found in the Coppo village area, and in the Barru District; Garessi Hamlet, Garessi Village, Pao Hamlet, and Lipukasi Village. The distribution of these rocks is characterized by its light gray and weathered grayish-brown color, with white spots (leucite) components. The $K_2O$ content of the rocks ranges from 1.48% - 2.10% (Muksin et al. 2015).

Potassium rock requires a slow weathering process to release available potassium from the mineral. The process can be accelerated by microbes that have ability in solubilizing the potassium from the rocks. The potassium-solubilizing microbes can accelerate the weathering process of potassium-carrying minerals and release potassium into an available form in the soil so that it can be absorbed by plants (Zörb et al. 2014). The dissolution mechanism by the microbes that changing potassium from insoluble or unavailable structural form into absorbable potassium for plants is claimed through organic acid production (Meena et al. 2013). The organic acids produced by the potassium-solubilizing microbes depend on the characteristics of the microbes and the carbon sources. In addition to organic acids, the microbes also produce vitamins, amino acids and several growth regulators that can help plant growth, namely indole-3-acetic acid (IAA) and gibberellic acid (GA3) (Bagyalakshmi 2012; Rahim et al. 2015).

Fungi can dissolve potassium bound to mineral rocks thereby increasing the availability of potassium in the soil (Prajapati et al. 2012). Mineralization of potassium by fungi takes place through chelating reactions of mineral elements, acid hydrolysis, and secretion of macromolecules and polymers which play an important role in releasing potassium from the potassium minerals (Meena et al. 2016). Previous studies have shown the potential of some fungi in solubilizing potassium such as *Aspergillus terreus* (Matthew and Tallapragada 2017). *Fomitopsis meliae* and *Aspergillus tubingensis* demonstrated the ability to dissolve potassium in dry soil (Kasana et al. 2017), *Aspergillus terreus, A. niger, Glomus mosseae, G. intraradices,* and *Penicillium* sp. were capable of dissolving the potassium mineral into a form that available to plants (Sattar et al. 2019). These microbes are ubiquitous, and their availability depends on the structure, texture, organic matter, and other associated soil properties (Sindu et al. 2010). Many types of fungi can be isolated from the rhizosphere of cultivated plants. This fungi can stimulates plant growth so that it is included in the plant growth promoting fungi (PGPF) group (Abri et al. 2015). Some plant growth regulators such as IAA can also be produced by the fungi (Maor et al. 2004; Bose et al. 2014; Abri et al. 2015). The fungi are able to increase plant growth in root colonization functionally (Usha and Padmavathi 2013). In other study, fungal isolates have been shown to produce siderophores, IAA, catalase enzyme activity and have the ability as biocontrol agents (Abri et al. 2015). Several genus of fungi isolated from the soil rhizosphere are known to have the ability to produce hormones including *Phanerochaete chrysosporium*, *Aeschynomene*, and *Colletotrichum gloeosporioides* (Astriani et al. 2014; Imaningsih et al. 2021).

Several studies regarding the ability of potassium solubilizing microbes to dissolve potassium bound to potassium carrier minerals have been carried out including, Setiawati and Mutmainnah (2016) examining the ability of potassium-solubilizing microbes bound to leucite rocks originating from Situbundo district, East Java and leucite starch in sugarcane growing areas. Other study evaluated the microbial ability to dissolve potassium from sources of potassium feldspar on ex-mining land (Pratama et al. 2016). Based on an investigation by Muksin et al. (2015), from the Indonesian Center for Geological Resources, there are deposits of potassium minerals, namely leucite, which are found in Barru Regency, South Sulawesi. Despite the potential of these mineral rocks with its potassium-solubilizing fungi, studies on this region are still lacking.

To achieve optimal plant growth, it is necessary to explore more microorganisms that have the ability to dissolve potassium, one of which is potassium-solubilizing fungal communities. Preparation of biofertilizers using beneficial fungi is a positive aspect related to sustainable agriculture (Sattar et al. 2019). In the present investigation deals with isolation of fungi from the rhizosphere of plant vegetation growing at the location of potassium rock deposits in Barru District and characterization of the fungi to dissolve potassium from the leucite rock potassium sources.

## MATERIALS AND METHODS

### Soil sampling

Soil samples were collected from the location of the leucite rock source at three sites ie. Salomoni and Pao hamlet located in Lipukasi Village, and Garessi hamlet located in Garessi Village. Both villages are located in Tanete Rilau District, Regency of Barru. Soil sampling was carried out in the area around plant roots of several different types of plants at each soil sampling location. Sampling was conducted by digging the soil to a depth of 0 to 20 cm in the rhizosphere. Soil was taken as much as 100 g for fungal isolation and 250 g for soil analysis. Soil samples were put in paper bag and labelled according to the first letter of the plant vegetation and the sampling location. Soil chemical analysis consists of: pH, nitrogen (N), phosphorus (P), potassium (K) total and exchangeable K (K-exch). Measurement of total potassium and exchangeable potassium was carried out using atomic adsorption spectrophotometer (AAS).

### Isolation of potassium-solubilizing fungi

Isolation of the potassium solubilizing fungi was carried out by modifying method by Prajapati et al. (2012); Pratama et al. (2016) using Alexandrov agar media. Prior to isolation, soil samples were dried followed by incubation of 10 g of the soil sample into 90 mL of Alexandrov broth media that had been added with chloramphenicol for 7 days. The incubated soil sample was diluted using the dilution method by adding 1 mL of media from the incubation to 9 mL of distilled water ($10^{-1}$), the steps were repeated until the dilution $10^{-5}$ was obtained. Isolation of the fungi was based on the plate spread method. Alexandrov agar media added with chloramphenicol was poured and spread over the entire surface of the Petridish and allowed to solidified. A total of 0.1 mL of the dilution was put onto a Petri plate containing Alexandrov's media and then spread over the entire surface of the media and incubated for 4 to 7 days. Each fungus that growed and formed a clear zone was purified using Alexandrov agar media with $K_2HPO_4$ and Barru Leucite rock, as a source of potassium, to grow 1 type of fungus.

### Qualitative and quantitative estimation of potassium

Qualitative test was carried out by culturing the isolates on Alexandrov agar media added with potassium sources from the Leucite rocks and $K_2HPO_4$. Observations of the fungal growth was carried out starting on the fourth day after planting the fungus, and continued on the seventh day, the tenth day and the thirteenth day after microbial planting. The value of the dissolution index (IP) was calculated each time of observation (four times).

The observed variables were the diameter of the fungus growth and the diameter of the clear zone formed by the fungus. In qualitative tests, the quality of microbes was observed from the value of the dissolution index (IP). The higher the value of the dissolving index of the fungus, the better the ability of the fungus to dissolve potassium. The value of the dissolution index (IP) was calculated based on the formula (Khandeparker's selection ratio) as used by Prajapati et al. (2012).

$$Dissolution\ Index\ (IP) = \frac{Diameter\ of\ clear\ zone}{Diameter\ of\ the\ colony}$$

Quantitative test was carried out by inoculating the fungus on liquid Aleksandrov media added with potassium sources from the Barru leucite rocks and $K_2HPO_4$ rocks. The media was mixed and added with aquadest to the desired volume limit. After thoroughly mixed, the media was put into a 25 mL bottle and then sterilized in an autoclave at 121°C for 15 min. Subsequently, the isolates were inoculated into liquid media and grown for 7 days. Measurements were carried out by separating the supernatant from fungal cells using a centrifuge for 25 min at a speed of 2500 rpm. The supernatant was then filtered to determine exchangeable potassium (K-exch.), which was analyzed using AAS. The results of K-exch show the ability of the fungi to dissolve potassium quantitatively.

**Production of Indole-3-acetic acid and Gibberellic acid**

Tests for IAA hormone production were carried out by growing fungal isolates on potato dextrose broth (PDB) media with the addition of L-tryptophan 100 mg/L, then the fungal cultures were incubated in the dark at 160 rpm for 5 days. The supernatant was taken after centrifugation on the sixth day and then 2 mL of the supernatant was added to 4 mL of Salkowski reagent (12 g $FeCl_3$ in 429 mL $H_2SO4$) in a test tube, then stored for 24 h at room temperature. The appearance of a pink color in the test tube indicates the production of IAA. Absorbance was measured by UV-VIS spectrophotometer with a wavelength of 535 nm (Rahim et al. 2015).

The GA3 hormone production was measured using Borrow's standard methods (Rahim and Suherman 2019). Five pieces of isolate from the potato dextrose agar (PDA) media were taken with Cork Borer, grown on PDB media, and incubated at room temperature for 7 days. Following the incubation, the culture was centrifuged at 8000 rpm for 10 min, and 15 mL was transferred into a test tube with addition of 2 mL of zinc acetate solution. After 2 min, 2 mL of potassium ferrocyanide solution was added and centrifuged at 8000 rpm for 10 min. Five milliliters of the supernatant was added with 5 mL of 30% hydrochloric acid and incubated at room temperature for 75 min. Blanks were prepared with 5% hydrochloric acid. The absorbance was measured at a wavelength of 254 nm using a UV-VIS spectrophotometer. The GA concentration was compared with the standard GA curve (Sigma-Aldrich).

## RESULTS AND DISCUSSION

**Soil sample characteristics**

Soil samples were taken from the rhizosphere of several different types of plants from the sampling sites. The sites were dominated with perennial trees such as teak (*Tectona grandis*), cashew (*Anacardium occidentale*), burflower-tree (*Neolamarkcia cadamba*), Mango tree (*Mangifera indica*), and sugar palm (*Arenga pinnata*) (Table 1). Other annual plants found in the sites were Rice (*Oryza sativa*), banana (*Musa paradisiaca*), and elephant grass (*Pennisetum purpureum*).

Soils at the sampling sites are classified as acidic to very acidic soils with pH ranged from 4.71 to almost 6. Potassium-solubilizing fungi can be found in soils with a pH of 4.71-5.95 (Table 2). According to Lay (1994) cited in Setiawati and Mutmainnah (2016), potassium solubilizing microbes in soil can grow in the pH range of 2-8 and fungi can grow well in the acidic pH range. Pao site in Lipukasi village showed the highest total K and exchangeable potassium (K-exch.) content of 12.25 mg/100g and 0.35 cmol/g, respectively.

**Potassium-solubilizing fungi**

Isolation of fungi from the rhizosphere of plant vegetation originating from 3 hamlets resulted in 64 fungi. The growth of the potassium-solubilizing fungi was indicated by the presence of a clear zone on the media surrounding the fungus. There were 34 isolates of potassium-solubilizing fungi obtained from soil samples which showed a clear zone. Each isolate with the best growth and clear zone formation was tested for its ability to dissolve potassium contained in potassium-carrying minerals, hence there were 22 fungi tested in the next stage.

**Table 1.** Location and vegetation of soil sampling sites in Tanete Rilau District, Barru Regency

| Location | Site | Vegetation |
|---|---|---|
| Lipukasi village | Salomoni | Teak (*Tectona grandis*) |
| | | Cashew (*Anacardium occidentale*) |
| | | Sugar Palm (*Arenga pinnata*) |
| | Pao | Teak (*Tectona grandis*) |
| | | Burflower (*Neolamarkcia cadamba*) |
| | | Banana (*Musa paradisiaca*) |
| | | Mango (*Mangifera indica*) |
| | | Rice (*Oryza sativa*) |
| Garessi village | Garessi | Elephant grass (*Pennisetum purpureum*) |
| | | Cashew (*Anacardium occidentale*) |

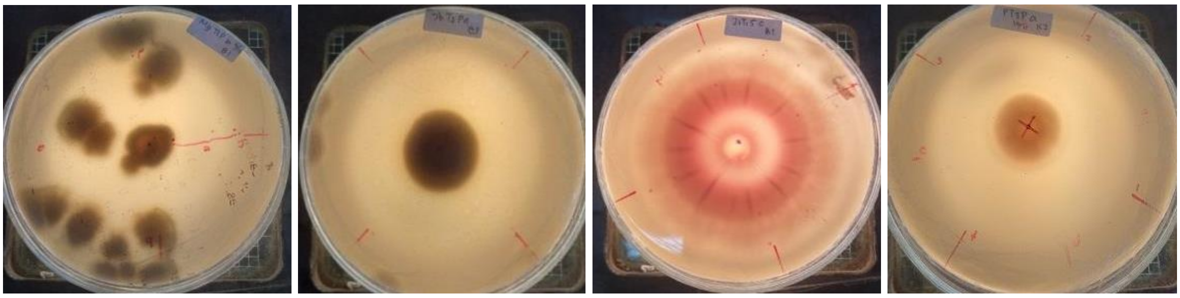
**Table 2.** Soil chemical properties on the study sites

| Location | pH | K total (mg/100g) | K-exch. (cmol/g) | N (%) | P (ppm) |
|---|---|---|---|---|---|
| **Salomoni** | 5.95 | 6.96 | 0.23 | 0.19 | 9.85 |
| Pao | 5.82 | 12.25 | 0.35 | 0.08 | 7.25 |
| Garessi | 4.71 | 9.23 | 0.22 | 0.12 | 6.45 |

**Table 3.** The qualitatively test of the potassium-solubilizing fungi on the Aleksandrov medium at day 13 (last observation)

| Isolate | $K_2HPO_4$ | | | Leucite | | |
|---|---|---|---|---|---|---|
| | d (cm) | D (cm) | D/d | d (cm) | D (cm) | D/d |
| J2T1Sa | 5.3 | 0.7 | 0.1 | 6.8 | 0.8 | 0.1 |
| MgT1Pb | 0.8 | 2.6 | **3.1** | 1.3 | 2.3 | **1.8** |
| JbT2Pp | 5.3 | 1.8 | 0.4 | 6.5 | 1.5 | 0.2 |
| JbT2Pd | 3.2 | 1.6 | 0.5 | 4.5 | 1.1 | 0.2 |
| JM1Sa | 5.7 | 1.0 | 0.2 | 8.4 | 0.8 | 0.1 |
| RgGb | 4.1 | 1.4 | 0.4 | 4.1 | 1.4 | 0.3 |
| PT3Pa | 2.8 | 1.7 | **0.6** | 4.8 | 1.8 | 0.4 |
| JbT2Pa | 3.1 | 1.7 | **0.5** | 3.3 | 1.7 | **0.5** |
| JbT2Pq | 5.1 | 1.1 | 0.2 | 5.2 | 0.8 | 0.2 |
| J1T1Sc | 4.7 | 1.0 | 0.2 | 8.2 | 0.7 | 0.1 |
| PsT2Pe | 8.4 | 1.0 | 0.1 | 4.8 | 1.1 | 0.2 |
| PsT2Pd | 4.5 | 1.4 | 0.3 | 4.1 | 1.4 | 0.3 |
| J4Ge | 8.4 | 1.7 | 0.2 | 8.4 | 1 | 0.1 |
| M2T2Gc | 8.4 | 0.9 | 0.1 | 8.4 | 0.9 | 0.1 |
| JM1Sb | 8.4 | 1.7 | 0.2 | 8.4 | 1.3 | 0.2 |
| JM1Sc | 3.5 | 1.4 | 0.4 | 4.2 | 1.3 | 0.3 |
| JsT1Pa | 5.3 | 1.0 | 0.2 | 5.8 | 1.2 | 0.1 |
| RgGd | 7.5 | 1.6 | 0.2 | 6.1 | 0.5 | 0.1 |
| PT3Pe | 1.7 | 2.1 | **1.2** | 2.7 | 2.0 | **0.7** |
| J4T1Gb | 8.4 | 0.8 | 0.2 | 8.4 | 0.7 | 0.1 |
| PT1Pd | 8.4 | 0.8 | 0.2 | 8.4 | 0.7 | 0.1 |
| Rg Gc | 1.1 | 2.4 | **2.4** | 1.6 | 2.1 | **1.3** |

Note: d: colony diameter (cm); D: diameter of clear zone (cm); D/d: dissolution index.



**MgT1Pb** **MgT1Pb** **J2t1sa** **PT3P a**

**Figure 1.** Observation of potassium-solubilizing fungal isolates

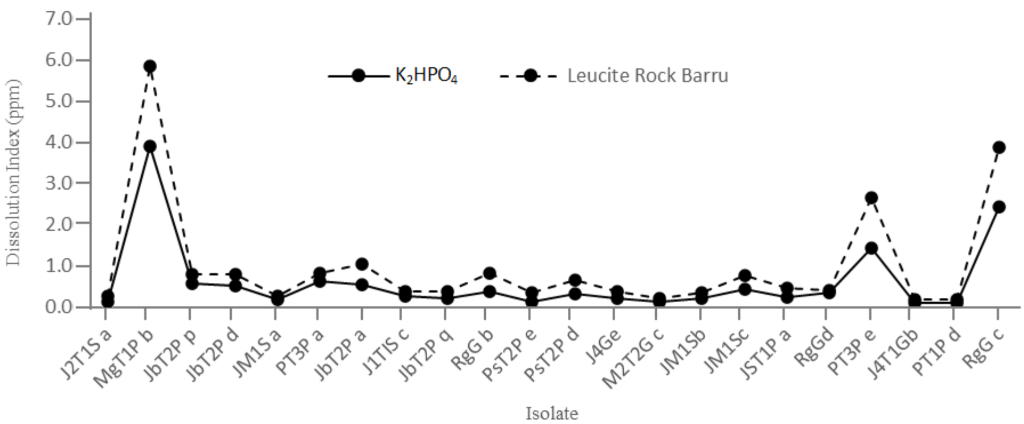



**Figure 2.** Average dissolution index (IP) of potassium-solubilizing fungi with $K_2HPO_4$ (solid line) and Barru leucite rocks (dashed line) as potassium source

**Qualitative test of potassium solubilizing ability on Aleksandrov medium**

Twenty-two isolates were grown on Aleksandrov Agar Media with a source of potassium from Barru tuff leucite which contained 3.24% $K_2O$ and $K_2HPO_4$. Twenty-two fungi that were tested for qualitatively dissolving potassium on solid Aleksandrov agar media with $K_2HPO_4$ and Barru leucite rock as a source of potassium had varied growths, as well as the ability to form clear zones (Table 3; Figure 1). Fungi that have good growth do not necessarily have good clear zone formation. Some fungi form large clear zones but small growth diameters. This is due to the ability of the fungus to form a low clear zone and the clear zone that is formed is then covered with large fungal growth (Mutmainnah 2013).

The fungi with the larger growth diameters were J4T1Gb and PT1Pd, but these fungi formed the lower clear zone compared to other fungi. Meanwhile, MgT1Pb fungal isolate has the ability to form the largest clear zone but smaller growth diameter than other isolates. According to Rajawat et al. (2014), microbes that grow and form clear zones on Aleksandrov media are assumed to be microbes capable of dissolving potassium.

The value of the dissolution index depends on the ratio of the diameter of the clear zone to the diameter of the growth of the fungus. The results of the qualitative test with the highest dissolution index value (D/d) by the fungus were MgT1Pb, RgGc, PT3Pe, PT3Pa, JbT2Pa, JbT2Pd, JbT2Pp. The higher the dissolution index, the higher the ability to dissolve potassium.

Microbes in dissolving potassium can be classified based on the dissolution index, namely low (IP<2), medium (IP 2 <4) and high (IP>4) (Marra et al. 2011). Based on the dissolution index value of the potassium-solubilizing fungi, the potassium source derived from the leucite rock was classified as low ranging from 0.1-1.8, the diameter of the clear zone ranged from 0.7cm to 2.3cm, while the potassium source from $K_2HPO_4$ was classified as medium with the highest value of 3.1, the diameter of the clear zone was 0.7cm-2.4cm. Study by Mutmainnah et al. (2013) showed the ability of microbes to dissolve potassium for potassium sources from starch leucite rock with dissolution index ranging from 0.11 to 4.37, clear zone diameter ranging from 0.10cm to 5.19 cm, while the source of potassium from the leucite rock of Situbundo, the dissolution index of potassium solvent microbes ranged from 0.16 -4.59, the diameter of the clear zone ranged from 0.20cm - 5.21cm.

**Quantitative test of potassium-solubilization**

Twenty two selected fungi were tested quantitatively on liquid Aleksandrov media with potassium $K_2HPO_4$ and Barru leucite rock as source of potassium. The results of the quantitative test are the values of exchangeable potassium (K-exch.) (Table 4).

**Table 4.** Total exchangeable potassium (K-exch) in liquid Aleksandrov media with potassium sources of $K_2HPO_4$ and Barru Leucite rock

| Isolate | Barru leucite rock (ppm) | K2HPO4 (ppm) |
|---|---|---|
| J2T1Sa | 59.67 | 782.20 |
| MgT1pb | 69.33 | 764.60 |
| JbT2Pp | 58.00 | 752.40 |
| JbT2pd | 68.87 | 816.20 |
| JM1Sa | 57.67 | 691.20 |
| PT3Pa | 60.67 | 773.20 |
| JbT2Pa | 63.00 | 919.80 |
| J1T1Sc | 54.67 | 805.20 |
| JbT2Pq | 69.00 | 835.60 |
| Without Fungi | 68.67 | 712.00 |
| PT1Pd | 28.12 | 176.93 |
| PT3P e | 20.06 | 166.70 |
| JM1Sb | 37.73 | 205.45 |
| J4Ge | 30.04 | 183.52 |
| RgG b | 24.29 | 205.45 |
| J4T1g b | 24.47 | 172.84 |
| M2T2G c | 33.51 | 178.86 |
| RgGd | 38.82 | 184.55 |
| JsT1P a | 27.29 | 160.68 |
| PsT2P d | 41.55 | 166.70 |
| JM1Sc | 25.33 | 182.50 |
| PsT2P e | 36.12 | 207.39 |
| RgGc | 12.64 | 165.34 |

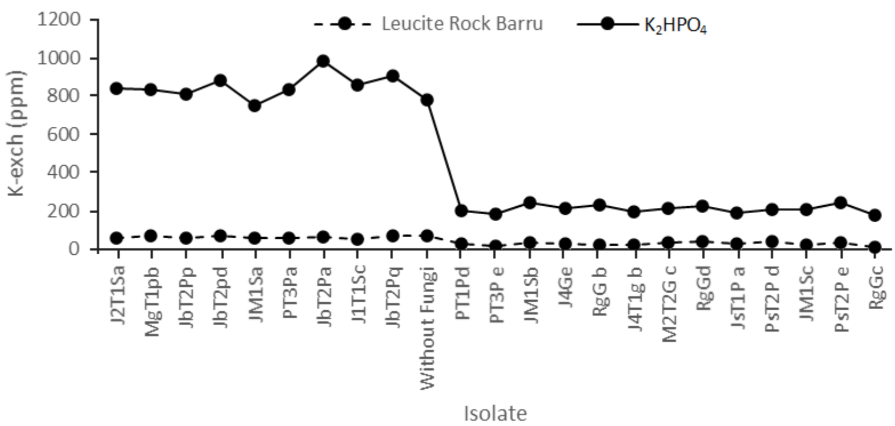



**Figure 3.** The amount of exchangeable potassium (K-Exch.) in liquid Aleksandrov media with potassium sources of $K_2HPO_4$ (solid line) and Barru leucite rocks (dashed line)

The exchangeable potassium (K-Exch.) in liquid Aleksandrov media with $K_2HPO_4$ as the potassium sources were greater than the exchangeable potassium (K-Exch.) resulted from Leucite Barru source (Figure 3). This is because Barru leucite is a mineral that is difficult to dissolve while $K_2HPO_4$, which is a source of soluble potassium. All isolates had the ability to dissolve potassium against Leucite sources with dissolved potassium concentrations of 12.64 ppm to 69.33 ppm. The highest dissolved potassium (K-Exch.) isolate was MgT1Pb at 69.33 ppm. The fungal isolate showed the highest amount of exchangeable potassium (K-Exch.) in liquid Aleksandrov media with potassium source of $K_2HPO_4$ was JbT2Pa with a total of 919.8 ppm. Research conducted by Setiawati and Mutmainnah (2016) showed the highest concentration of dissolved K produced by fungal isolate from leucite starch and Situbundo sources were 18.7 mg/L and 4.59 mg/L, respectively. On the other research by Kasana et al. (2017), it was found that the dissolved K shown by isolates from feldspar sources was 7.1 mg/L, which was higher than the control treatment or without fungus. It is suspected that the activity of the fungus can dissolve potassium from insoluble potassium bonds present in the Aleksandrov liquid media. The exchangeable K result with the addition of the fungus was lower than the control presumably because this fungus uses dissolved potassium in the media for its life activities. Potassium-solubilizing microbes can dissolve potassium from insoluble potassium bonds in a medium through the secretion of organic acids and utilize the dissolved potassium for the formation of new cells, resulting in immobilization potassium by microbes (Basak 2009).

**Indole-3-acetic acid production**

Twenty two potassium solvent fungi were tested for their ability to produce IAA. The IAA test results show that the average IAA production was 0.15 - 6.82 ppm produced by potassium-solubilizing fungal isolate (Figure 2). The fungus isolate that was able to produce the highest IAA was PsT2Pe at 6,820 ppm. Research results by Abri et al. (2015) shows the average production of IAA ranged from 0.556 to 2.190 mg/L by fungal isolates from Pare Kaloko aromatic rice rhizosphere, and 0.048-1.810 mg/L on Pare Bau fungal isolates. While study conducted by Imaningsih et al. (2021) showed that IAA concentration produced by the rhizosphere fungal isolates of IRZ15 was 8,46 ± 0,26 mg/L. The difference in IAA production could be caused by the type of fungus and the origin of the different potassium solvent fungus isolate (Abri et al. 2015).

**Gibberellic acid (GA3) production**

The ability of potassium solvent fungus isolate to produce GA3 was tested by measuring the absorbance of the isolate supernatant and comparing it with a standard curve. Twenty-two fungal isolates generally had the ability to produce GA3. GA3 hormone is useful for plant growth and physiological processes. This process includes seed germination, seedling emergence, stem and leaf growth, flower induction and flower and fruit growth (Bottini et al. (2004) cited in Rahim and Suherman (2019).

The measurement of GA3 the production of potassium solubilizing fungal isolates ranged from 0.423 ppm to 4.116 ppm (Figure 4). Isolate RgGd produced the highest concentration of GA3 hormone, which was 4.116 ppm, then RgGc (4.009ppm), J1T1Sc (3.951ppm), Jm1Sa (3.926ppm), JbT2Pa (3.888ppm), and MgT1Pb (3,869ppm) respectively.

**Discussion**

In the present study, fungal isolation was carried out on Alexandrov's media using two kinds of potassium sources, namely $K_2HPO_4$ and Barru leucite rocks as soluble and insoluble potassium source respectively. The fungus that grows and has the ability to form a clear zone were assumed to be a fungus that capable of dissolving the insoluble potassium contained in the Aleksandrov agar media. According to Ghevariya and Desai (2014), microbes that are able to form a clear zone are considered as potassium-solubilizing microbes. Results from the recent study indicate the presences of the potassium-solubilizing fungi from the native Barru leucite deposits.

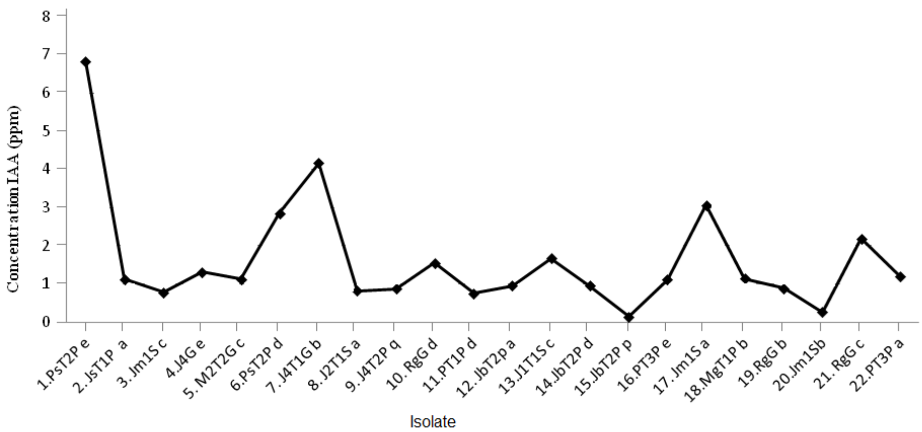



**Figure 4.** Production of IAA by the potassium solubilizing fungus

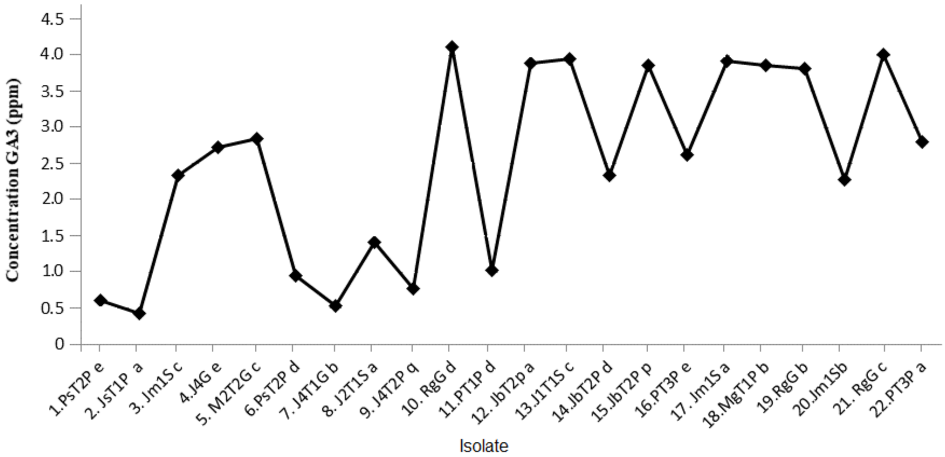



**Figure 4.** Gibberellic acid (GA3) production of fungal potassium solubilizing fungal isolates

The results of the K-exch. test also show that some fungi produced K-exch. with values was higher or lower than the amount of K-exch. in the control media (without the fungus). The presence of higher K-exch value was assumed due to the ability of the fungus to dissolve potassium from potassium bonds that are previously in its insoluble from in the liquid media, while the lower K-exch. result might be attributed to the utilization of the dissolved potassium in the medium by the fungus for its life activities. According to Basak and Biswas (2009), potassium-solubilizing microbes can dissolve potassium from insoluble potassium bonds through the secretion of organic acids and the microbes can utilize the dissolved potassium further for the formation of new cells, resulting in immobilization of the potassium. Ability of the fungi to releases potassium was basically depending on the species and production of organic acids. The mechanism in dissolving potassium by the microbes in providing potassium that can be absorbed by plants from the insoluble form of potassium is through the production of organic acids (Meena et al. 2014). In addition, the potassium-solubilizing microbes also produce growth regulators that can help plant growth, namely IAA and GA3 (Bagyalakshmi et al. 2012). The fungal isolates showed different production of IAA and GA3 for each isolate. It is suspected that there are different types of fungi and the origin of the isolates with different potassium solvents. The reaction that changes color to red indicates the ability of the fungus to metabolize L-tryptophan to IAA. IAA produced by microbes from plant roots, especially in the rhizosphere area, has a metabolic pathway through synthetic L-tryptophan (Patil 2011).

It can be concluded from the recent study that isolated fungal strains have ability to dissolve potassium from an insoluble potassium-carrying mineral source (Barru Leucite). The solubility zone ranged from 0.7 to 2.3 cm, the dissolving index ranged from 0.1 - 1.8 in the solid medium. Quantitative test for potassium-solubilizing fungi, carried out in liquid medium containing potassium mineral from Leucite rock showed that released exchangeable-K ranging from 12.64 to 69.33 ppm. All isolates produced IAA and GA3. The IAA and GA3 produced by the potassium-solubilizing fungi ranged from 0.15 to 6.82 ppm and 0.423-4.116 ppm, respectively.

## REFERENCES

Abri, Kuswinanti T, Sengin LE, Sjahrir R. 2015. Production of indole acetic acid (IAA) hormone from fungal isolates collected from rhizosphere of aromatic rice in Tana Toraja. Intl J Curr Res Biosci Plant Biol 2 (6): 198-201.

Astriani F. 2014. Selection of fungus isolates to produce iaa (indol acetic acid) hormones from rimbo panjang peat soil, Kampar Regency. JOM FMIPA 1 (2): 1-11. [Indonesian]

Bagyalakshmi B, Ponmurugan P, Marimuthu S. 2012. Influence of potassium solubilizing bacteria on crop productivity and quality of tea (*Camellia sinensis*). Afr J Agric Res 7 (30): 4250-4259. DOI: 10.5897/ajar11.2459.

Basak BB, Biswas DR. 2009. Influence of potassium solubilizing microorganism (*Bacillus mucilaginosus*) and waste mica on potassium uptake dynamics by sudan grass (*Sorghum vulgare* Pers.) grown under two Alfisols. Plant Soil 317 (1): 235-255. DOI: 10.1007/s11104-008-9805-z.

Bose A, Shah D, Keharia H. 2013. Production of indole-3-acetic-acid (IAA) by the white rot fungus *Pleurotus ostreatus* under submerged condition of Jatropha seedcake. Mycology 4 (2): 103-111. DOI: 10.1080/21501203.2013.823891.

Bottini R, Cassán F, Piccoli P. 2004. Gibberellin production by bacteria and its involvement in plant growth promotion and yield increase. Appl Microbiol Biotechnol 65 (5): 497-503. DOI: 10.1007/s00253-004-1696-1.

Dasan AS. 2012. Compatibility of agrochemicals on the growth of phosphorous mobilizing bacteria *Bacillus megaterium* var. phosphaticum potassium mobilizing bacteria *Frateuria aurantia*. Appl Res Dev Inst J 6 (13): 118-34.

Ghevariya KK, Desai PB. 2014. Rhizobacteria of sugarcane: in vitro screening for their plant growth promoting potentials. Res J Recent Sci 3 (IVC-2014): 52-58.

Imaningsih W, Rahayu ND, Hakim SS. 2021. Endophytes and rhizosphere fungi from galam (*Melaleuca cajuputi* Powell.) which has the potential to produce indole acetic acid (IAA). J Trop Biodivers Biotechnol 6 (2): 1-13. DOI: 10.22146/JTBB.61594.

Kasana RC, Panwar NR, Burman U, Pandey CB, Kumar P. 2017. Isolation and identification of two potassium solubilizing fungi from arid soil. Intl J Curr Microbiol Appl Sci 6 (3): 1752-1762. DOI: 10.20546/ijcmas.2017.603.201.

Maor R, Haskin S, Levi-Kedmi H, Sharon A. 2004. In planta production of indole-3-acetic acid by *Colletotrichum gloeosporioides* F. sp.

*aeschynomene*. Environ Microbiol 70: 1852-1854. DOI: 10.1128/AEM.70.3.1852-1854.2004.

Marra LM, de Oliveira SM, Soares CRFS, de Souza Moreira FM. 2011. Solubilisation of inorganic phosphates by inoculant strains from tropical legumes. Sci Agric 68 (5): 603-609. DOI: 10.1590/S0103-90162011000500015.

Matthew T, Tallapragada P. 2017. Isolation, characterization and identification of potassium solubilizing fungi from rhizosphere soil in bangalore. Intl J Biol Pharm Allied Sci 6 (5): 931-940.

Meena VS, Maurya BR, Verma JP, Aeron A, Kumar A, Kim K, Bajpai VK. 2015. Potassium solubilizing rhizobacteria (KSR): Isolation, identification, and K-release dynamics from waste mica. Ecol Eng 81: 340-347. DOI: 10.1016/j.ecoleng.2015.04.065.

Meena VS, Maurya BR, Verma JP, Meena RK, Meena SK. 2016. Potassium solubilizing microorganisms for sustainable agriculture. In: Meena VS (eds.). Potassium solubilizing microorganisms for sustainable agriculture. Springer India. DOI: 10.1007/978-81-322-2776-2.

Meena VS, Maurya BR, Bahadur I. 2013. Potassium solubilization by bacterial strain in waste mica. Bangladesh J Both 43 (2): 235-237. DOI: 10.3329/bjb.v43i2.21680.

Mutmainnah L. 2013. Inventory and test of potassium dissolving ability by potassium solubilizing microbes from the rhizosphere of sugarcane (*Saccharum* sp.). [Thesis]. University of Jember, Jember. [Indonesia]

Muksin I, Kusdarto, Marza DR. 2015. General exploration of potassium rocks in Barru and Tanete Rilau sub-districts, Barru district, South Sulawesi province. Proceedings of Geological Resources Activities in 2015. Center for Geological Resources of Indonesia.

Patil NB, Gajbhiye M, Ahiwale SS, Gunja AB, Kapadnis BP. 2011. Optimization of indole 3-acetic acid (IAA) production by Acetobacter diazotrophicus Ll isolated from sugarcane. Intl J Environ Sci 2 (1): 295-302.

Prajapati K, Sharma M, Modi H. 2012. Isolation of two potassium solubilizing fungi from ceramic industry soils. Life Sci Leaf 5: 71-75.

Pratama D, Anas I, Suwarno. 2016. Ability of potassium-solubilissing microbes to solubilise feldspar and their effects on sorghum growth. Malays J Soil Sci 20: 163-175.

Rahim I, Suherman H. 2019. Production of gibberellins from decaying fungi from the cocoa plant. Proceedings of the 2019 National Seminar on Multidisciplinary Synergy of Science and Technology 2.

Rahim I, Kuswinanti T, Asrul L, Rasyid B. 2015. Growth rate and indole acetic acid production of several fungal rot isolates. Intl J Sci Res 4 (6): 1636-1638.

Rajawat MVS, Singh S, Saxena AK. 2014. A new spectrophotometric method for quantification of potassium solubilized by bacterial cultures. Indian J Exp Biol 52 (3): 261-266.

Sindu S, Dua S, Verma MK, Khandelwal A. 2010. Growth promotion of legumes by inoculation of rhizosphere bacteria. In: Khan MS, Zaidi A, Musarrat J (eds.). Microbes for legume improvement. Springer, Vienna. DOI: 10.1007/978-3-211-99753-6_9.

Sattar A, Naveed M, Ali M, Zahir ZA, Nadeem SM, Yaseen M, Meena VS, Farooq M, Singh R, Rahman M, Meena HN. 2019. Perspectives of potassium solubilizing microbes in sustainable food production system: A review. Appl Soil Ecol 133: 146-159. DOI: 10.1016/j.apsoil.2018.09.012.

Sembiring M, Sabrina T. 2022. Diversity of potassium solving microbes on andisol soil affected by the eruption of Mount Sinabung, North Sumatra, Indonesia. Biodiversitas 23 (4): 1759-1764. DOI: 10.13057/biodiv/d230406.

Setiawati TC, Mutmainnah L. 2016. Solubilization of potassium containing mineral by microorganisms from sugarcane rhizosphere. Agric Agric Sci Proc 9: 108-117. DOI: 10.1016/j.aaspro.2016.02.134.

Usha S, Padmavathi T. 2013. Effect of plant growth promoting microorganisms from rhizosphere of *Piper nigrum* L. Intl J Pharm Biol Sci 4 (1): 835-846.

Wang Y, Wu WH. 2013. Potassium transport and signaling in higher plants. Annu Rev Plant Biol 64 (1): 451-476. DOI: 10.1146/annurev-arplant-050312-120153.

Zörb C, Senbayram M, Peiter E. 2014. Potassium in agriculture - Status and perspectives. J Plant Physiol 171 (9): 656-669. DOI: 10.1016/j.jplph.2013.08.008.