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Bio-activation of waste mica through potassium solubilizing bacteria and rice residue

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ABSTRACT

This article aims to demonstrate the increase in availability of potassium (K) from mica through bio-activation using different strains of potassium solubilizing bacteria (KSB) and rice residue incorporation and comparing it with standard K-fertilizer i.e. muriate of potash (MOP). The effects of mica, rice residue and KSB on wheat biomass yield, K uptake and available K in soil were assessed through a pot culture study at research farm of ICAR-Indian Agricultural Research Institute, New Delhi (2019). Results reveal that mica application @ 50 and 100 mg/kg soil significantly improved the biomass yield and K uptake by wheat as compared to treatments without mica application. Rice residue incorporation @ 2 g/kg soil had significant role in improvement of biomass yield, K uptake by wheat and available K in soil as compared to no residue treatments. Amongst the two isolated strains of KSB (JHKSB1 and JHKSB4) and one standard strain (*Bacillus* sp.), all were found equally effective in improving K availability from mica to the wheat crop. Mica, bio-activated via rice residue and KSB was able to improve relative agronomic efficiency and per cent K recovery from soil but it was not as effective as MOP. Thus, inherent K content in mica may be available to crops partly after bio-activation and it can be applied in conjunction with MOP for meeting the K requirement of the crop.

Keywords: Mica, Potassium, Potassium solubilizing bacteria, Rice residue, Wheat yield

Potassium (K) is an essential nutrient for plants and is vital in overall growth and developments of crops. Although K is not a constituent of any organic molecule it is involved in numerous biochemical and physiological processes. Potassium needs for plants are met through addition of K-fertilizers. About 90–98% of total soil K is found in different K-bearing minerals. However, plants can not use K in insoluble form. Moreover, rate of K release from K-minerals is too slow to meet crop needs. Lack of high-grade K-mineral deposits for production of commercial K-fertilizers forces India to import the entire K-fertilizers requirement from other countries like Canada, Germany, Russia, Belarus, Israel, etc. (Kafkafi *et al*. 2001, Basak *et al*. 2020). However, India is rich in having low-grade K-bearing mineral deposits like mica, but because of low total K content in it they are not economically feasible for K-fertilizer production. In this regard, bio-activation of these K-minerals can be one of the ways to efficiently use this underutilized reserve and thereby reduce the dependency of costly K-fertilizers.

Mica belongs to the family of 2:1 type of clay mineral (muscovite mica) with an ideal chemical formula of $K_2(Si_6Al_2)Al_4O_{20}(OH)_4$. Mica ores are obtained in the form of big blocks which are used after processing as insulators, lubricants, etc. Though mica has wide applicability in various fields, its use in agriculture is underexplored. About 75% of the total mica mined (Basak and Biswas 2009) is generated as waste during processing of raw mica. Though attempts have been made to utilize waste mica as an alternative source of K to plants, activation of mica using combination of organic source and potassium solubilizing bacteria (KSB) have not yet been explored as a source of K-fertilizer. Rice residue being a source of organic matter may help in maintaining the population of added inoculants for a longer period and it itself is a source of K which may further enhance K availability to crops. In this aspect, the current study was undertaken based on the hypothesis that K availability from waste mica will enhance through bio-activation using KSB and rice residue incorporation.

MATERIALS AND METHODS

The present study was carried out at the research farm of ICAR-Indian Agricultural Research Institute, New Delhi (2019). Bulk soil sample (0–15 cm) approximately 500 kg was collected from an uncultivated plot in Birsa Agricultural University, Ranchi, Jharkhand, located at 23º44′ N latitude

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and 85º32′ E longitude. The soil is classified as Typic Haplustalf having low available K. The soil sample was air-dried and passed through 5-mm sieve for pot culture experiment, and about 500 g of sample was ground with a wooden pestle and mortar and passed through 2-mm sieve for characterization of initial physicochemical parameters. Two strains of KSB isolated from mica mining areas of Koderma, Jharkhand (named as JHKSB1 and JHKSB4) and another strain of KSB (*Bacillus* sp.) obtained from Division of Microbiology, ICAR-IARI, New Delhi were used for the present study.

Rice residue was chopped into small pieces (~1 cm) and added @ 2 g/kg soil equivalent to 4.5 t/ha. The total nitrogen (N), phosphorus (P) and K content of rice residue used in the present experiment were 0.50%, 0.15% and 0.89%, respectively. The mica mineral was ground and passed through 1-mm sieve before further use. The water soluble K (WSK), ammonium acetate extractable K, 1 N HNO_3 extractable K and total K content of the mineral particles were 15.0, 24.6, 384 and 56000 mg K/kg, respectively. The effectiveness of three strains of KSB and rice residue incorporation was tested in a pot culture experiment at ICAR-IARI, New Delhi. Treatments consisting of factorial combinations of two levels of rice residue incorporations (0 and 2 g/kg soil), three rates of waste mica (M0, M50 and M100 corresponding to 0, 50 and 100 mg K/kg soil, respectively) and three bacterial cultures (JHKSB1, JHKSB4 and *Bacillus* sp.) were used along with an absolute control and standard MOP (@ 50 mg K/kg soil) treatment. The experiment was laid out in a completely randomized design with three replications.

Processed soil sample (4.5 kg/pot) was filled in glazed pots. The entire soil of a pot was emptied on a polythene sheet and mixed thoroughly as per the treatment combinations. Water was maintained at 50% of the field capacity. A uniform dose of N as urea @ 50 mg N/kg soil and P as NaH_2PO_4 @ 15 mg P/kg soil was also applied to each pot in solution form. Quantity of mica and rice residue was calculated and added to the soil according to the treatments. Microbial culture was added @ 20 mL of broth culture per pot (1.5×10^7 CFU/mL). Soil for all the different treatments were mixed thoroughly and was repacked in the respective pots and kept on the platform in the greenhouse ensuring proper drainage conditions and abundant of sunshine. Wheat (*Triticum aestivum*) var HD-2967 was selected as the test crop for pot culture experiment. This crop was chosen because its K requirement is high for optimum growth and yield. Twenty seeds of wheat per pot were sown on 23rd October, 2019 by dibbling. After sowing, water was sprayed to moisten the top soil. Thinning was done 10 days after sowing to maintain five healthy plants per pot. Irrigation was given as and when necessary. Proper care was taken to ensure healthy crop growth. Crop was harvested after maturity and biomass was recorded after sun drying the plant samples for 2–3 days. Thereafter, the samples were oven dried at 65±2ºC in hot air oven for 72 h, ground in Willey mill and stored in paper packets for further analysis.

Soil samples were collected from each pot after harvesting and were air-dried under shade, passed through 2-mm sieve and stored properly for analysis of available K. For initial physicochemical characteristics of the bulk soil, following parameters were analyzed. The soil *p*H was measured with a digital *p*H meter in 1:2.5:: soil: water suspensions (Jackson 1973). The proportion of sand, silt and clay in the soil samples were determined by hydrometer method (Bouyoucos 1962). Water soluble K (WSK) was extracted using distilled water (soil: water:: 1:5) with shaking time of 5 min. Exchangeable K (Exch-K) was determined

Table 1 Biomass yield (g/pot) of wheat grown in Alfisol from Ranchi as affected by waste mica, KSB and rice residue incorporation

Treatment	KSB			Mica			Mean
	JHKSB1	JHKSB4	*Bacillus* sp.	M0	M100	M100	
Rice residue (g/kg soil)							
0	18.0	16.9	17.4	16.9	17.2	18.2	17.4
2	19.8	21.0	20.9	17.3	22.9	21.6	20.6
Mica (mg K/kg soil)							
M0	17.2	17.2	16.9				
M50	19.5	20.3	20.3				
M100	19.9	19.4	20.4				
Mean	18.9	19.0	19.2	17.1	20.0	19.9	
MOP (Standard)	25.1						
Control (Absolute)	16.1						
CD (P=0.05)							
Rice residue		0.47	Rice residue × Mica			0.82	
Mica		0.57	Mica × KSB			0.82	
KSB		NS	Rice residue × KSB			NS	
Control vs rest		Sig	Rice residue × Mica × KSB			1.41	

by using 1 N ammonium acetate (soil: solution:: 1:5) as described by Hanway and Heidel (1952). Non-exchangeable K (NEK) was determined by boiling with 1 *N* HNO_3 (soil: solution:: 1:10) as described by Wood and deTurk (1941). The experimental soil had *p*H of 6.68 and EC 0.11 dS/m. Soil was loam in texture with WSK, Exch-K and NEK values of 5.98, 50.4 and 330 mg K/kg soil, respectively.

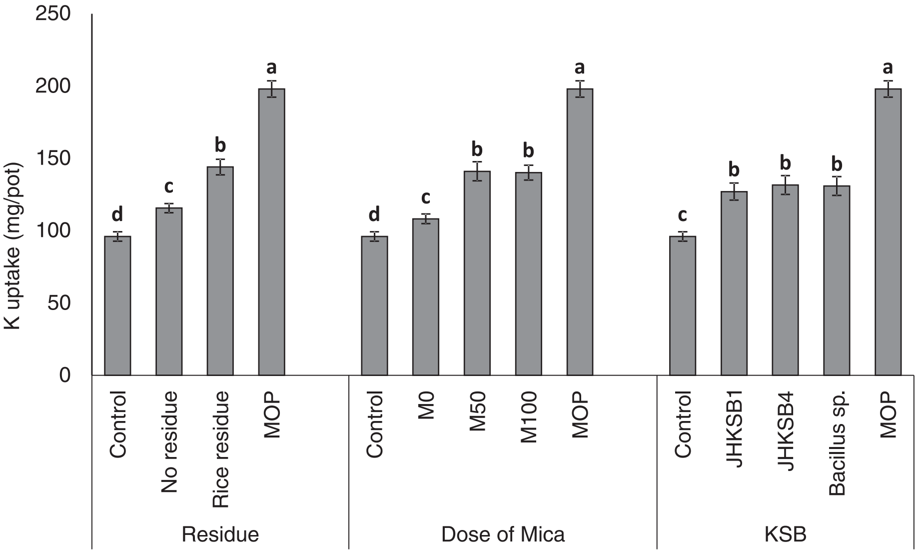

Fig 1 Potassium uptake by wheat (g/pot) grown in Alfisol of Ranchi as affected by rice residue, dose of mica and K-solubilizers. Different letters within each set of columns are significantly different at P=0.05, Error bars represents standard error.

RESULTS AND DISCUSSION

Potassium deficient soil when treated with mica, KSB and rice residue depicts an overall increase in the biomass of wheat as compared to absolute control (Table 1) thus, highlighting the importance of bio-activation of insoluble mica in improving the biomass yield of wheat. Potassium reserves in mica is in crystalline and insoluble form, its activation by KSB produces different organic acids which has the potential to cause K release from the mineral by directly dissolving K or chelating silicon ions to bring the K into solution form (Friedrich *et al*. 1991, Bennett *et al*. 1998, Basak and Biswas 2009, Biswas and Basak 2014). Decomposition of silicate minerals by *Bacillus mucilaginosus* in liquid culture was also studied by Liu *et al*. (2006) who reported that the bacterial strain was found to be effective in dissolving soil minerals and mica and simultaneously released K and SiO_2 from crystal lattice. Rice residue as a factor, also presents a higher biomass yield values over no residue pots as clear from their mean values (17.4 and 20.6 g/pot in no residue pots and rice residue treatment, respectively). This might be due the fact that with increase in period of growth of wheat crop (150 days), the residue incorporation may have undergone decomposition and released various organic acids in the process which in turn acts upon the mica particles to disintegrate it and make K available for crop uptake and growth.

Amongst different mica doses, mica applied @ 50 mg K/kg soil (M50) had significantly higher values over M0 treatments. Addition of mica provides a substrate for the organic acids released from KSB and residue decomposition to act upon it and release K. However, the biomass improvement was confined only up to M50. Further, increasing the mica dose had no significant increase over M50. This observation is contrary to the established fact that nutrient release will improve with increasing concentration of the nutrient source, however in this case, mica is insoluble and requires dissolving action of some acidic solutions in its vicinity. The concentration of acids released may be insufficient for further action on mica particles and therefore the maximum biomass had been restricted to the M50 dose. However, amongst all treatments, the MOP treated pots had recorded maximum yield as the entire amount of K in MOP is in water soluble form and except for the losses due to leaching majority of it is available to the plants for uptake which results higher biomass yield.

Total K content in straw ranged from 0.66–0.89% (data not presented) and in seeds the range was 0.27–0.35% clearly indicating that translocation of K is more to the straw than to seed of wheat (Fig 1). Effect of different factors was conspicuous with rice residue incorporation performing significantly better than no residue treatment and M50 and M100 dose of K application dominating the uptake by M0 treatments. Potassium uptake will improve when availability of K increases in the soil. Treating mica with different KSB and indirect effect of rice residue had definitely caused some dissolution of K from the minerals thereby causing higher K uptake by crops. Regarding, the potential of different KSB, all the three performed at par with each other in improving K uptake by crop.

The available K in soil after harvesting of wheat ranged from 44.8–117 mg K/kg soil in absolute control and MOP treatments, respectively (Table 2). All other pots treated with mica, KSB and rice residue had available K levels between these two extremes. Amongst different doses of mica, available K levels were comparable in M50 and M100 treatments, whereas both of them had higher available K over M0 treatment. Thus, reemphasizing the efficacy of mica addition in increasing available K. Incorporation of rice residue @ 2 g/kg soil was also able to improve the available K in soil which may be due to the release of inherent K from the straw upon decomposition and also indirectly through organic acids released during decomposition that may have triggered the release of K from mica. Potassium solubilizing bacteria also showed higher available K at flowering stage as

Table 2 Available K (mg K/kg soil) in soil after harvesting of wheat grown in Alfisol of Ranchi as affected by waste mica, KSB and rice residue

Treatment	KSB			Mica			Mean
	JHKSB1	JHKSB4	*Bacillus* sp.	M0	M100	M100	
Rice residue (g/kg soil)							
0	64.2	62.4	66.3	47.6	67.9	77.4	64.3
2	79.6	76.3	79.5	54.0	93.4	88.0	78.5
Mica (mg K/kg soil)							
M0	51.1	47.5	53.8				
M50	80.5	80.1	81.4				
M100	84.1	80.4	83.6				
Mean	71.9	69.4	72.9	50.8	80.7	82.7	
MOP (Standard)	117						
Control (Absolute)	44.6						

CD (P=0.05)			
Rice residue	1.43	Rice residue × Mica	2.49
Mica	1.76	Mica × KSB	NS
KSB	1.76	Rice residue × KSB	NS
Control vs rest	Sig	Rice residue × Mica × KSB	4.31

compared to control, but there were no significant differences (P=0.05) in terms of increase in available K levels amongst the three K-solubilizers. Irrespective of the treatments, the highest amount of available K was maintained in the MOP treated pot which clearly indicates that MOP application is the best way to improve the available K in soil. Other treatments could possibly improve the available K levels but not as efficiently as MOP.

This point is further clarified when relative agronomic efficiency (RAE) and per cent K recovery was calculated. Results showed that in comparison to MOP treated pots (RAE=100%), the RAE in mica treated pots were 43 and 42%, respectively, i.e. approximately half of MOP treatment (Fig 2). Similarly, the RAE in residue treatments was 50% which indicates that these treatments are 50% as effective as MOP in improving the yield of wheat. Relative agronomic efficiency was comparable in the three KSB strains i.e. 33, 32 and 31%, respectively.

Per cent K recovery was also calculated. In case of MOP, the per cent of K recovered was calculated to be 45%, whereas recovery was comparable among rice residue treatments, M50 and M100 treatments (22, 21 and 22%, respectively). The values were close to 50% of the recovery in MOP.

Correlation study of different parameters among each other as also conducted and it revealed that biomass yield of wheat was significantly and positively correlated (P=0.01) with K uptake (r=0.78**) by the crop, and also with available K at flowering stage (r=0.87**), available K also reflected a positive and significant correlation with K uptake (r=0.87**), indicating that increase in available K increases K uptake by plants and consequently improves crop biomass yield. All the parameters are related to each other positively and significantly.

The present results indicate that when avail K in soil is increased as a result of K solubilization from mica bio-activated with rice residue or KSB, the ability of wheat to take up K from soil is also enhanced and more K is taken up which results in better biomass yield. It is reported that complex interactions of soil mineralogical factors, and

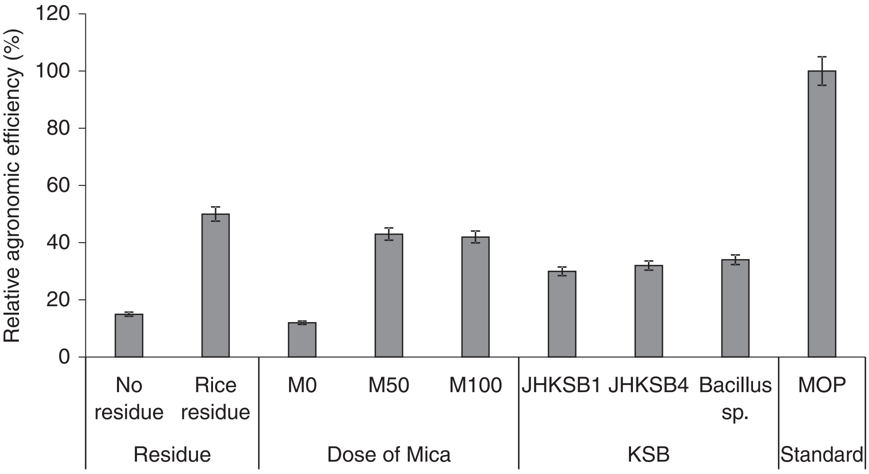

Fig 2 Relative agronomic efficiency of wheat grown in Alfisol of Ranchi as affected by rice residue, dose of mica and K-solubilizers. Error bars represents standard error.

biological processes, determine how readily structural K in soil minerals, or fixed K may become available for crop uptake (Hinsinger and Jaillard 1993, Wang *et al.* 2000). Benipal and Pasricha (2002) reported that cumulative K uptake was significantly related to exchangeable K released from soils.

Overall, this research demonstrated that mica can also be used as a potential source of K nutrition to plants like wheat after suitable activation through KSB strains and rice residue incorporation. The treatments can meet 50% of the requirement of K by the crop and the remaining 50% can be substituted through water-soluble K fertilizer like MOP thus reducing the cost incurred in the application of imported K-fertilizers. This research also brings out the comparable efficacy of the three strains of K-solubilizers in improving K availability to crops. In present scenario, India has large deposits of mica minerals, similarly rice residue availability is also high and its management is of major concern nowadays. Therefore, the present outcome may turn out to be economically feasible for adoption in the near future. It may be used as an alternative way to improve the solubility of mica and in turn help in improving K nutrition in crops.

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