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Effect of potassium (K) and potassium solubilizing bacteria (KSB) growth, yield, quality parameters and nutrient uptake by wheat (*Triticum aestivum* L.)

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Abstract
A field experiment entitled Effect of potassium and potassium solubilizing bacteria (KSB) on growth, yield, quality parameters and nutrient content of wheat (*Triticum aestivum* L.) Var. GW 366 was conducted on clayey soils of Junagadh having status of low available nitrogen and medium available phosphorus and potassium during *rabi* season of 2017-18 at Instructional Farm, Department of Agronomy, College of Agriculture, Junagadh Agricultural University, Junagadh. The experiment comprised of 16 treatments having four levels of potassium (K) (0, 30, 45 and 60 kg K_2O ha^{-1}) and four levels of potassium solubilizing bacteria (KSB) (0, 0.5, 1.0 and 1.5 lit ha^{-1}) carried out in factorial randomized block design (FRBD) replicated at thrice. The experimental results revealed that application of 60 kg K_2O ha^{-1} (K_3) with KSB 1 lit ha^{-1} (KSB_2) as soil application promoted growth parameters *viz*., grain & straw yield, number of effective tillers per meter row, total tillers per meter row, spikelet's per spike, spike length and also quality parameter like test weight, protein content was found significant influenced by 60 kg K_2O ha^{-1} with KSB 1 lit ha^{-1} (KSB_2) recorded this treatment over the 0 kg K_2O ha^{-1}. Potassium content in straw and grain at all stages significantly affected by 60 kg K_2O ha^{-1} with KSB 1 lit ha^{-1} (KSB_2) over control.

Keywords: Wheat, potassium and KSB, growth, yield, nutrient content

Introduction
Wheat is one of the most important grain crops which is belongs to *Poaceae* family and staple food crop of the world and emerged as the backbone of India's food security. Wheat is one of the second most significant cereal in India following rice, contributing substantially to the national food security by providing more than 50% of the calories to the people who mainly depend on it. It is grown all over the world for its wider adaptability and high nutritive value. In Gujarat, wheat occupies an area of 1.06 million hectares with a production of 3.052 million tonnes and productivity of 2.89 metric tones ha^{-1} (Anon., 2018) [2].
Potassium is one of 17 vital nutrients required for the growth and reproduction. Most of the K in soil exists in various insoluble rocks, minerals and sedimentary materials. Excessive usage of fertilizers leads to the leaching of nutrients from the soil and contributes to environmental pollution, without corresponding increases in yield. Potassium fixed with in soil and not easily meet to crop. Although most agricultural soils have large amounts of K, these are immobilized and mostly become unavailable. Hence, very limited concentration of K is available to plants due to this K is deficient in soils. The amount of potassium present in the soil solution is often smaller than the wheat crop requirement for potassium. With the use of K solublizing microbes the concentration of available K ions can be increase in the soil which may further reduce K deficiency (Barker *et al*., 1998) [5].
There is many research has done in previous year on KSB and their working mechanism. The use of KSB as a biological fertilizer is a hotspot for the study of agriculture and environmental conservation (Deng *et al*., 2003) [6]. The application of organo-minerals with the combination of silicate bacteria for enhancing plant growth and yield of maize and wheat first reported by Aleksandrov *et al*. (1967) [1]. Therefore, the use of KSB in agricultural practice would not only offset the high cost of manufacturing potassic fertilizers but would also mobilize insoluble

fertilizers in the soils to which they are applied. It would also mobilize insoluble fertilizers in the soils to which they are applied. Use of phosphate bio-fertilizers decreases the detrimental effects of phosphate fertilizers on crop and soil health.

Materials and Methods

The field experiment was conducted during 2017-18 at Instructional Farm, Department of Agronomy, JAU, Junagadh situated at at 21.5° N latitude and 70.5° E longitude with an altitude of 60 m above the mean sea level on the wastern side at the foothill of mountain 'Girnar' under South Saurashtra Agro-climatic region of Gujarat. The soil of experimental site was clayey in texture with pH 8.1 and EC 0.52 dS m^{-1}. The soil was low in available nitrogen (245.00 kg ha^{-1}), medium in available phosphorus (41.10 kg ha^{-1}) and potassium (279.00 kg ha^{-1}). The experiment was laid out in factorial randomized block design with three replications. The experiment comprised of 16 treatments having four levels of potassium (K) (0, 30, 45 and 60 kg K_2O ha^{-1}) and four levels of potassium soluiblizing bacteria (KSB) (0, 0.5, 1.0 and 1.5 lit ha^{-1}) carried out in factorial randomized block design (FRBD) replicated at thrice and variety is GW 366.

Results and Discussion

(1) Yield and yield parameter (Grain & Straw yield)

(A) Effect of potassium (K) & KSB

A perusal of data revealed that different levels of potassium exhibited their significant influence on grain yield. The application of 60 kg K_2O ha^{-1} (K_3) was recorded significantly the highest grain yield (4561 kg ha^{-1}) & straw yield (6717) which was statistically equivalent to the treatment comprising soil application of 45 kg K_2O ha^{-1} (K_2). While in KSB, significantly the highest grain yield (4475 kg ha^{-1}) & straw yield (5881) was recorded with application of KSB 1 lit ha^{-1} soil application (KSB_2), which was found statistically at par with application of KSB 1.5 lit ha^{-1} soil inoculation (KSB_3).

This results also close conformity with Archna *et al.* (2007) reported that KSB is able to solubilize inorganic source of K like muriate of potash by means of production of organic acids in order to improve yield in maize crop. Bagyalakshami *et al.* (2012) [4] reported that application of indigenous KSB formulation with various doses of potash fertilizers with N and P enhanced green leaf yield and productivity in tea. The increase in yield might be due to the solubilization of nutrients in the soil by producing organic acids by KSB.

Possible direct effect of the bacteria on plant growth via phytohormones, the bacteria mainly acted by an indirect way via mineral weathering, which increased the amount of available nutrients for the plant and/or a direct effect of the bacteria on plant roots by phytohormones which stimulate the formation of lateral roots and absorbent root hairs (Mikhailouskaya *et al.* (2009) [8] in winter rye, spring wheat and winter triticale, Zhanga *et al.* (2013) [11] in okra and Konga (2014) [7] in tobacco.

Table 1: Effect of potassium and KSB levels on yield, growth and quality parameters of wheat

Treatments	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	No. of effective tillers per meter row	No. of total tillers per meter row	Spikelet per spike	Spike length (cm)	Test weight (g)	Protein content (%)
Potassium (K)								
K_0: 0 kg K_2O ha^{-1}	3600	4246	52.43	73.85	12.82	6.78	50.29	10.41
K_1: 30 kg K_2O ha^{-1}	3660	5137	54.26	80.33	13.98	7.22	52.45	10.80
K_2: 45 kg K_2O ha^{-1}	4458	6374	72.63	86.43	15.28	8.23	59.48	11.52
K_3: 60 kg K_2O ha^{-1}	4561	6717	75.99	88.83	16.06	8.62	61.03	11.94
S.Em ±	107	140	1.22	2.17	0.35	0.25	0.84	0.41
C.D. at 5%	310	403	3.53	6.28	1.03	0.73	2.42	NS
Potassium solublizing bacteria (KSB)								
KSB_0: KSB 0 lit ha^{-1}	3614	5339	58.60	76.90	14.10	7.43	54.02	10.61
KSB_1: KSB 0.5 lit ha^{-1}	3864	5441	61.38	80.27	14.34	7.49	54.28	10.69
KSB_2: KSB 1 lit ha^{-1}	4475	5881	71.66	88.11	14.87	8.17	57.99	12.05
KSB_3: KSB 1.5 lit ha^{-1}	4326	5812	68.68	84.22	14.83	7.77	56.96	11.32
S.Em ±	107	140	1.22	2.17	0.35	0.25	0.84	0.41
C.D. at 5%	310	403	3.53	6.28	NS	NS	2.42	NS
K x KSB								
S.Em ±	261	279	2.44	4.35	0.71	0.51	1.68	0.81
C.D. at 5%	755	NS	7.06	NS	NS	NS	NS	NS
CV %	11.90	8.61	6.50	9.14	8.46	11.40	5.20	12.64

(B) Interaction effect of potassium (K) and KSB

Examination of data showed that interaction effect of different levels of potassium and KSB on grain yield was found significant. Wherein, the treatment combination K_3KSB_2 (60 kg K_2O ha^{-1} + KSB 1 lit ha^{-1}) recorded significantly the highest grain yield (5184 kg ha^{-1}), however it remained statistically at par with the treatment combinations K_2KSB_3 (45 kg K_2O ha^{-1} + KSB 1.5 lit ha^{-1}), K_2KSB_2 (45 kg K_2O ha^{-1} + KSB 1 lit ha^{-1}) and K_3KSB_3 (60 kg K_2O ha^{-1} + KSB 1.5 lit ha^{-1}). Whereas, the treatment combination K_0KSB_0 (0 kg K_2O ha^{-1} + KSB 0 lit ha^{-1}) registered significantly lowest grain yield. While in straw yield interaction found non significant.

Table 2: Interaction effect of potassium and KSB levels on grain yield (kg ha^{-1}) of wheat

KSB (lit ha^{-1}) / Potassium(kg ha^{-1})	KSB_0 (KSB 0)	KSB_1 (KSB 0.5)	KSB_2 (KSB 1.0)	KSB_3 (KSB 1.5)
K_0 (0 K_2O)	3382	3617	3793	3608
K_1 (30 K_2O)	3395	3772	3826	3647
K_2 (45 K_2O)	3797	3926	5097	5014
K_3 (60 K_2O)	3883	4141	5184	5034
S.Em ±	214			
C.D. at 5%	619			

(2) Growth parameter

(A) Effect of potassium (K) & KSB

Significantly the highest number of effective tillers m^{-1} (75.99) spikelet per spike (16.06), total tillers m^{-1} (88.83), spike length (8.62 cm)was showed with application of 60 kg K_2O ha^{-1} (K_3), which was statistically equivalent to the treatment comprising soil application of 45 kg K_2O ha^{-1} (K_2). On the contrary, the 0 kg K_2O ha^{-1} (K_0) registered significantly the lowest result. Patel *et al.* (2007) [9] showed that the application of potassium 60 kg K_2O ha^{-1} significantly increased the number of effective tillers per meter row length (81.41) over control and 30 kg K_2O ha^{-1}. Patel *et al.* (2007) [9] showed that the application of potassium 60 kg K_2O ha^{-1} significantly increased the number of effective tillers per meter row length (81.41) over control and 30 kg K_2O ha^{-1}.

With regard to observation treatment KSB 1 lit ha^{-1} soil application (KSB_2) established its superiority by recording significantly the highest number of effective tillers m^{-1} row (71.66), total tillers m^{-1} (88.11) & Various levels of KSB did not compel significant influence on number of spikelet per spike & spike length.

(B) Interaction effect of potassium (K) & KSB

Combined effect of potassium & KSB found non significant on growth parameter except no. of effective tillers per meter row.

(3) Quality parameter

(A) Effect of potassium (K) & KSB

A perusal of data revealed that different levels of potassium indicated their significant influence on test weight. Significantly the highest 1000-grain weight (61.03 g) was noticed with treatment of 60 kg K_2O ha^{-1} (K_3), which was statistically at par to the treatment comprising soil application of 45 kg K_2O ha^{-1} (K_2).

Significantly the highest test weight (57.99 g) was exerted with treatment of KSB 1 lit ha^{-1} soil application (KSB_2), which was found statistically comparable with application of KSB 1.5 lit ha^{-1} soil inoculation (KSB_3).

Scutiny of data showed that interaction effect of different levels of potassium and KSB was found non-significant on test weight.

An examination of data revealed that different levels of potassium, KSB & their did not exert their significant influence on protein content.

Table 3: Interaction effect of potassium and KSB levels on no. of effective tillers m^{-1} row of wheat

KSB (lit ha^{-1}) / Potassium(kg ha^{-1})	KSB_0 (KSB 0)	KSB_1 (KSB 0.5)	KSB_2 (KSB 1.0)	KSB_3 (KSB 1.5)
K_0 (0 K_2O)	42.47	51.73	58.63	56.90
K_1 (30 K_2O)	56.93	57.30	61.53	61.27
K_2 (45 K_2O)	63.27	63.87	82.93	80.47
K_3 (60 K_2O)	71.73	72.63	83.53	76.07
S.Em ±	2.44			
C.D. at 5%	7.06			

(4) Nutrient content in wheat

(A) Effect of potassium & KSB

As evident of data show that not significantly effect on the most nitrogen and phosphorus content in grain & straw found non significant at different levels of potassium and KSB. Various treatments of potassium did exhibit their significant influence on potassium content in straw at 30, 60, 90 DAS and at harvest (grain & straw). Among different treatments of potassium, application of 60 kg K_2O ha^{-1} (K_3) recorded significantly the highest potassium content in straw and grain. While Potassium content in straw at 30 DAS remained unaffected under KSB levels. While, under the given treatment schedule treatment KSB 1 lit ha^{-1} (KSB_2) potassium content in straw 60, 90 DAS and at harvest (grain & straw) recorded significant.

(B) Interaction effect of potassium & (KSB)

Combined effect between different levels of potassium and KSB failed to manifest significant effect on nitrogen, phosphorus and potassium content in straw and grain.

Table 4: Effect of potassium and KSB levels on nutrient content (Nitrogen, Phosphorus, Potassium) of wheat

Treatments	Potassium content (%)					Phosphorus content (%)		Nitrogen content (%)	
	30 DAS	60 DAS	90 DAS	At harvest		At harvest		At harvest	
				Grain	Straw	Grain	Straw	Grain	Straw
Potassium (K)									
K_0: 0 kg K_2O ha^{-1}	2.77	2.15	1.69	0.383	1.17	0.358	0.120	1.67	0.368
K_1: 30 kg K_2O ha^{-1}	2.82	2.21	1.72	0.420	1.23	0.359	0.131	1.73	0.401
K_2: 45 kg K_2O ha^{-1}	2.96	2.38	1.87	0.518	1.31	0.399	0.139	1.84	0.411
K_3: 60 kg K_2O ha^{-1}	3.04	2.42	1.89	0.524	1.35	0.400	0.140	1.91	0.418
S.Em ±	0.04	0.04	0.03	0.013	0.02	0.015	0.006	0.07	0.017
C.D. at 5%	0.13	0.11	0.08	0.037	0.06	NS	NS	NS	NS
Potassium solublizing bacteria (KSB)									
KSB_0: KSB 0 lit ha^{-1}	2.82	2.21	1.72	0.421	1.22	0.346	0.122	1.70	0.367
KSB_1: KSB 0.5 lit ha^{-1}	2.92	2.24	1.76	0.440	1.24	0.378	0.132	1.71	0.393
KSB_2: KSB 1 lit ha^{-1}	2.93	2.37	1.87	0.501	1.32	0.402	0.143	1.93	0.423
KSB_3: KSB 1.5 lit ha^{-1}	2.91	2.34	1.82	0.484	1.28	0.391	0.132	1.81	0.415
S.Em ±	0.04	0.04	0.03	0.013	0.02	0.015	0.006	0.07	0.017
C.D. at 5%	NS	0.11	0.08	0.037	0.06	NS	NS	NS	NS
K x KSB									
S.Em ±	0.09	0.08	0.05	0.025	0.04	0.029	0.012	0.13	0.034
C.D. at 5%	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV%	5.28	5.71	5.25	9.55	5.86	13.42	15.61	12.64	14.69

(5) Nutrient uptake by wheat

(A) Effect of potassium & KSB

Different fertilization of potassium and KSB treatments produce significant effect on nitrogen, phosphorus and potassium (30, 60, 90 and at harvest) uptake by straw & grain. Significantly the highest nitrogen, phosphorus and potassium (30, 60, 90 and at harvest) uptake by grain and straw was recorded with the treatment K_3 (60 kg K_2O ha^{-1}) with KSB 1 lit ha^{-1} (KSB_2), but it was found statistically at par with the treatments K_2 (45 kg K_2O ha^{-1}) with KSB 1.5 lit ha^{-1} soil inoculation (KSB_3).

Sheng *et al.* (2003) [10] reported that in cotton and rapeseed root and shoot growth and potassium content was increased by 30 and 26 percent respectively and in chilli crop increased biomass and K uptake due to inoculation of potash solubilizer in China.

(B) Interaction effect of potassium & (KSB)

The interaction effect of different levels of potassium and KSB was found non-significant as far as nitrogen, phosphorus and potassium uptake by straw & grain is concerned. Except nitrogen uptake by grain and potassium uptake by straw at 90 DAS found significant at different levels potassium and KSB levels.

Table 5: Effect of potassium and KSB levels on nutrient uptake (Nitrogen, Phosphorus, Potassium) by wheat

Treatments	Potassium uptake (mg $plant^{-1}$)					Phosphorus uptake		Nitrogen uptake	
	30 DAS	60 DAS	90 DAS	At harvest (kg ha^{-1})		At harvest (kg ha^{-1})		At harvest (kg ha^{-1})	
				Grain	Straw	Grain	Straw	Grain	Straw
Potassium (K)									
K_0: 0 kg K_2O ha^{-1}	43.61	162.5	239.00	13.81	49.33	12.94	5.10	60.04	15.62
K_1: 30 kg K_2O ha^{-1}	61.82	188.7	276.99	15.38	63.20	13.13	6.78	63.31	20.72
K_2: 45 kg K_2O ha^{-1}	93.71	228.2	355.51	23.34	83.30	17.91	8.83	83.55	26.07
K_3: 60 kg K_2O ha^{-1}	99.66	240.4	368.75	24.15	90.72	18.51	9.40	87.50	28.05
S.Em ±	2.21	5.60	6.43	0.77	2.73	0.68	0.39	3.63	1.07
C.D. at 5%	6.37	16.17	18.58	2.22	7.89	1.97	1.13	10.50	3.08
Potassium solublizing bacteria (KSB)									
KSB_0: KSB 0 lit ha^{-1}	64.16	184.18	286.57	15.33	65.36	12.83	6.62	61.58	19.52
KSB_1: KSB 0.5 lit ha^{-1}	72.80	195.87	294.33	17.14	68.09	15.03	7.19	66.08	21.55
KSB_2: KSB 1 lit ha^{-1}	83.72	223.10	333.86	22.93	78.43	17.93	8.61	87.62	25.07
KSB_3: KSB 1.5 lit ha^{-1}	78.11	216.89	325.48	21.28	74.67	16.71	7.70	79.11	24.33
S.Em ±	2.21	5.60	6.43	0.77	2.73	0.68	0.39	3.63	1.07
C.D. at 5%	6.37	16.17	18.58	2.22	7.89	1.97	1.13	10.50	3.08
K x KSB									
S.Em ±	4.41	11.20	1.54	5.46	0.04	1.37	1.37	7.27	2.14
C.D. at 5%	NS	NS	4.45	NS	NS	NS	NS	20.99	NS
CV%	10.23	9.46	13.92	13.21	5.86	15.15	15.15	17.10	16.35

(6) Interaction effect of potassium and KSB on potassium uptake by wheat straw at 90 DAS

Examination of data notice that interaction effect of different levels of potassium and KSB on potassium uptake by grain was found significant. Wherein, the treatment combination K_2KSB_2 (45 kg K_2O ha^{-1} + KSB 1 lit ha^{-1}) recorded significantly the highest potassium uptake by grain (30.67 kg ha^{-1}), however it remained statistically at par with the treatment combinations K_3KSB_3 (60 kg K_2O ha^{-1} + KSB 1.5 lit ha^{-1}) and K_3KSB_3 (60 kg K_2O ha^{-1} + KSB 1 lit ha^{-1}). Whereas, the treatment combination K_0KSB_0 (0 kg K_2O ha^{-1} + KSB 0 lit ha^{-1}) registered significantly the lowest potassium uptake by grain (12.00 kg ha^{-1}).

Table 6: Potassium uptake by grain

KSB (lit ha^{-1}) / Potassium(kg ha^{-1})	KSB_0 (KSB 0)	KSB_1 (KSB 0.5)	KSB_2 (KSB 1.0)	KSB_3 (KSB 1.5)
K_0 (0 K_2O)	12.00	13.72	14.87	14.64
K_1 (30 K_2O)	13.23	14.35	17.13	16.82
K_2 (45 K_2O)	18.36	19.25	30.67	25.06
K_3 (60 K_2O)	17.74	21.21	29.06	28.59
S.Em ±	1.54			
C.D. at 5%	4.45			

(7) Interaction effect of potassium and KSB on nitrogen uptake by wheat grain

An obvious from data presented that interactive effect of different levels of potassium and KSB was found significant as far as nitrogen uptake by grain is concerned. Wherein, the treatment combination K_2KSB_2 (45 kg K_2O ha^{-1}+ KSB 1 lit ha^{-1}) recorded significantly the highest nitrogen uptake (111.96 kg ha^{-1}) by grain, however it remained statistically at par with the treatment combinations K_3KSB_3 (60 kg K_2O ha^{-1}+ KSB 1.5 lit ha^{-1}), K_3KSB_2 (60 kg K_2O ha^{-1} + KSB 1 lit ha^{-1}) and K_2KSB_3 (45 kg K_2O ha^{-1}+ KSB 1.5 lit ha^{-1}). Whereas, the treatment combination K_0KSB_0 (0 kg K_2O ha^{-1} + KSB 0 lit ha^{-1}) registered significantly least nitrogen uptake (55.53 kg ha^{-1}) by grain.

Table 7: The treatment combination K0KSB0

KSB (lit ha^{-1}) / Potassium(kg ha^{-1})	KSB_0 (KSB 0)	KSB_1 (KSB 0.5)	KSB_2 (KSB 1.0)	KSB_3 (KSB 1.5)
K_0 (0 K_2O)	55.53	60.32	63.31	60.99
K_1 (30 K_2O)	57.82	64.59	67.98	62.85
K_2 (45 K_2O)	58.32	66.28	111.96	97.64
K_3 (60 K_2O)	74.67	73.12	107.24	94.94
S.Em ±	7.19			
C.D. at 5%	20.99			

Conclusion
It could be concluded that soil application of potassium at 60 kg K_2O ha^{-1} and KSB 1 lit ha^{-1} enhanced grain yield and quality of wheat and maintaining soil fertility with saving of fertilizer dose of potash.

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