Potential of Bacteria from Goat Rumen as Growth Promoters, Nitrogen Fixation, Phosphate Solubilizers, and Biological Controllers

Rusmini¹, La Mudi¹, Zainal Abidin², Daryono², Rusli Anwar³

¹(1. Department of Food Crop Production Technology, State Agriculture Polytechnic of Samarinda, Samarinda, 75131, Indonesia; 2. Department of Plantation Crop Cultivation, State Agriculture Polytechnic of Samarinda, Samarinda, 75131, Indonesia; 3. Department of Plantation Management, State Agriculture Polytechnic of Samarinda, Samarinda, 75131, Indonesia)

Abstract: Modern agriculture faces the challenge of global climate change; therefore, plants cannot adapt to dynamic environmental conditions. Of course, alternatives are needed that utilize the potential of microbes from goat rumen. The research aims to obtain microbes from the goat rumen that have dual abilities as plant growth promoters (PGP), nitrogen fixation, phosphate soluble, and biological control agents. A total of 15 isolates were tested for their ability to act as growth promoters and biocontrol agents. Research on testing bacterial isolates as PGP was conducted using a completely randomized design with two replications. Bacteria from goat rumen can stimulate growth by producing the IAA hormone (29.00–207.67 ppm), fix nitrogen, dissolve phosphate (9 isolates), increase the root length of soybean seedlings, and be biocontrol agents in producing cellulase and protease enzymes (13 isolates) and amylase enzymes. These goat rumen bacteria are different from those in previous research that focused only on the use of goat rumen as a liquid fertilizer and its role as a biodecomposer. This research has an impact on increasing plant growth, the cycle of nutrients, especially the N and P elements, and biological control agents, thus supporting sustainable agriculture.

Keywords: bacteria; goat rumen; enzymes

山羊瘤胃细菌作为生长促进剂、固氮剂、磷酸盐溶解剂和生物控制剂的潜力

Rusmini¹, La Mudi¹, Zainal Abidin², Daryono², Rusli Anwar³

¹(1. 三马林达国立农业理工学院粮食作物生产技术系, 三马林达, 75131, 印度尼西亚)

Received: January 17, 2024 / Revised: February 5, 2024 / Accepted: March 11, 2024 / Published: March 29, 2024

Fund projects: The Directorate General of Vocational Education of the Ministry of Education, Culture, Research, and Technology (The 2023 Beginner Matching Fund Grant)

About the authors: Rusmini (1981), female, La Mudi (1989), male, Department of Food Crop Production Technology, State Agriculture Polytechnic of Samarinda, Indonesia, E-mails: min9964@rocketmail.com, lamud89@gmail.com; Zainal Abidin (1994), male, Daryono (1980), male, Department of Plantation Crop Cultivation, State Agriculture Polytechnic of Samarinda, Indonesia, E-mails: Zainal.abidinberau@gmail.com, vydaryono16@yahoo.com; Rusli Anwar (1970), male, Department of Plantation Management, State Agriculture Polytechnic of Samarinda, Indonesia, E-mail: rusli.anwar78@gmail.com

Corresponding author: Rusmini (1981), female, Department of Food Crop Production Technology, State Agriculture Polytechnic of Samarinda, Indonesia, E-mail: min9964@rocketmail.com

This article is an open-access article distributed under the terms and conditions of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0)
2. 三马林达国立农业理工学院种植园作物栽培系, 三马林达, 75131, 印度尼西亚
3. 三马林达国立农业理工学院种植园管理系, 三马林达, 75131, 印度尼西亚

摘要:
现代农业面临全球气候变化挑战；因此，植物无法适应动态的环境条件。当然，需要利用山羊瘤胃微生物潜力的替代方案。该研究旨在从山羊瘤胃中获得具有植物生长促进剂（前列腺素），固氮、磷溶和生物防治双重能力的微生物。总共测试了15个分离株作为生长促进剂和生物防治剂的能力。将细菌分离株作为前列腺素进行测试的研究是采用完全随机设计并重复两次进行的。来自山羊瘤胃的细菌可以通过产生国际航空协会激素（29.00–207.67百万分之一）来刺激生长、固氮、溶解磷酸盐（9个分离株）、增加大豆幼苗的根长，并作为生产纤维素酶和蛋白酶的生物防治剂（13个分离株）和淀粉酶。这些山羊瘤胃细菌与之前的研究不同，之前的研究仅关注山羊瘤胃作为液体肥料的用途及其作为生物分解剂的作用。这项研究对促进植物生长、营养物质循环（尤其是氮元素和磷元素）以及生物防治剂产生影响，从而支持可持续农业。

关键词：细菌；山羊瘤胃；酶

1 Introduction
Modern agriculture is facing increasingly complex challenges, including increasing global population, climate change, and the unsustainability of the use of conventional agricultural inputs. To achieve environmentally friendly and sustainable agricultural development, research on the potential of microorganisms that play multiple roles needs to be optimized. Microbes can act as plant growth-promoting agents [1,2], nitrogen fixation [3,4], phosphate solubilizers [5–7] and biological controls are very important [8–10]. Bacteria originating in the goat rumen are the focus of attention because this special digestive environment is a unique habitat for microorganisms with great potential.
Optimizing plant growth requires adequate nutrient availability, and nitrogen fixation and phosphate solubilization are vital processes in providing essential nutrients for plants [11,12]. Bacteria from goat rumen are believed to have the ability to increase the availability of nitrogen and phosphate in soil through complex biological mechanisms. In addition, as biological controllers, these bacteria can control plant pathogens and promote the balance of agricultural ecosystems [13–15].
Although research has been conducted regarding the potential of bacteria from goat rumen, there is no deep understanding of the unique properties and capabilities of microorganisms in goat rumens and their potential to increase agricultural productivity. The use of bacteria from goat rumen is also in line with the development of sustainable organic agriculture.
In this context, this research is more directed toward exploring the potential of bacteria from goat rumen as plant growth promoters, nitrogen fixators, phosphate solubilizers, and biological controllers. By understanding the role of these bacteria more deeply, innovative solutions can be found to increase agricultural efficiency, reduce dependence on inorganic fertilizers, and strengthen the resilience of the agricultural system as a whole [16,17].
This research aims to determine the potential of bacteria from the goat rumen as growth promoters, their ability to fix nitrogen and dissolve phosphate, and their potential as biological control agents.

2 Materials and Methods
2.1 Research Design
This research was conducted for two months at the Agronomy Laboratory of the Samarinda State Agricultural Polytechnic. The research was conducted using an experimental design. Research on testing bacterial isolates as plant growth promoters was conducted using a completely randomized design with two replications.
2.2 Research Object
The objects of this research were microbes from goat rumen, which were tested for their ability to stimulate plant growth (IAA synthesis, N fixation, phosphate solvents), application to soybean seedlings (root length), and ability to act as biological controllers (producers of cellulase, amylase, and protease enzymes).

2.3 Research Procedures
The research procedures are briefly presented in the following flowchart:

![Experimental flowchart](image)

2.3.1 IAA Production
The bacteria were grown in a liquid NA medium containing L-tryptophan, shaken, and incubated at room temperature for 24 h. The culture was centrifuged for 10 min at 10,000 rpm to obtain the supernatant. Next, 0.5 mL of the supernatant was taken using a micropipette, and 2 mL of Salkowski’s reagent (made from a mixture of distilled water, H$_2$SO$_4$, and FeCl$_3$) was added. The mixture was then incubated in a dark room for 15 min. Furthermore, the absorbance value was measured using a spectrophotometer at a wavelength of 510 nm.

2.3.2 N Fixation and P Solubility
The ability of bacteria to fix N was tested using media consisting of MgSO$_4$ 7H$_2$O (25 g), NaMoO$_4$ 2H$_2$O (0.01 g), FeSO$_4$ 7H$_2$O (0.01 g), CaCl$_2$ (0.1 g), MnSO$_4$ 5H$_2$O (0.01 g), and K$_2$HPO$_4$ in NaCl buffer (5 mL). Pure isolates aged 48 h and grown on the media were then incubated at room temperature for 4 days, and the growth of the growing bacteria was observed. An indicator of isolates capable of fixing N was the growth of isolates in media without N through changes in the turbidity level of the liquid medium.

The ability of bacteria to dissolve phosphate was tested using Pikovskaya’s agar test medium with tricalcium phosphate (TCP) as the phosphate source. The composition of Pikovskaya’s agar medium per liter consisted of glucose (10 g), KCl (0.2 g), NaCl (0.2 g), MgSO$_4$ (0.1 g), FeSO$_4$ (2.5 mg), MnSO$_4$ (2.5 mg), (NH$_4$)$_2$SO$_4$ (0.5 g), yeast extract (0.5 g), and agar (15 g). The mixture of ingredients was heated on a hot plate until it boiled, and the pH of the media was adjusted to 7.2 with KOH 5 N, then sterilized using an autoclave at 121°C for 15 min at pressure of 2 psi. After the sterile test media was poured into a Petri dish (φ 9 cm), holes were made with a cork puncturer and filled with 0.2 mL of the rhizome isolates tested. The test medium with bacteria was incubated for 3 days in an incubation room at 28°C. The phosphate solubilizing ability of the tested isolates was qualitatively evaluated on the basis of the formation of halos around the holes containing bacterial suspensions.

2.3.3 Hydrolase Enzyme Activity Test
The hydrolase activity test was carried out by testing the cellulase, amylase, and protease enzymes. 24-h-old isolates on NA plates were inoculated using the well method using a corer borer into carboxymethyl cellulose (CMC) medium in a Petri dish and incubated at 30°C for 48 h. Cellulolytic activity testing was performed with iodine solution. The cellulolytic activity of bacteria is indicated by the formation of a clear zone around the colony after being dipped with iodine and left for 3-5 minutes. Cellulase enzyme activity is characterized by the presence of a clear zone.

Meanwhile, the amylase enzyme test was carried out by inoculating bacteria into YPS (yeast peptone soluble starch) medium. The composition of the YPS medium (yeast extract 1 g, peptone 2.5 g, KH$_2$PO$_4$ 1.5 g, MgSO$_4$ 7H$_2$O 0.25 g, CaCl$_2$ 0.05 g, and 2H$_2$O 10 g) was dissolved in 500 ml of distilled water, and then 10 g of Bacto Agar was added to the agar medium.

If bacteria have amylase enzyme activity, a clear zone will appear around the bacterial colony, whereas if bacteria do not have amylase enzyme activity, a clear zone will appear.

The protease enzyme test was performed using qualitative analysis. Qualitative analysis of proteinase activity was performed by colonizing bacterial isolates on Skim Milk Agar (SMA) medium. SMA medium contains peptone (0.1% w/v), NaCl (0.5% w/v), agar (2.0% w/v), and skim milk (10% v/v). Proteinase activity is
indicated by a halo (clear zone) around the bacterial colony\textsuperscript{[19]}.

2.3.4 Seed Treatment

Before using the seeds, the Devon 1 variety of soybean seeds was first sterilized using 2% NaOCl for 5 min, rinsed with sterile distilled water three times, and dried in a laminar airflow cabinet for 30 min. The seed treatment used the seed biopriming technique, in which the seeds were placed in 20 mL of suspension of goat rumen bacteria for 24 h at 28°C. After treatment, the seeds were dried in a laminar airflow cabinet for 30 min and ready for germination. The seed germination test media used sterile husk charcoal, which was placed in a germination box with a size of 20 x 20 x 6.5 cm (length x width x height). Furthermore, 30 treated seeds germinated in germination tanks for 7 days.

Observation of root length was carried out on the 7th day after harvest by removing the soybean sprouts, cleaning and drying them, and then measuring the roots using a ruler.

2.4 Observation and Measurement

Observations and measurements in this research cover the ability of microbes to synthesize IAA, fix nitrogen, dissolve phosphate, produce cellulase, amylase, and protease enzymes, and the appearance of soybean sprout roots.

2.5 Data Analysis

The observed data on the ability of bacteria were analyzed descriptively. The observed data on root length were analyzed using variance and continued with the DMRTα = 0.05 test. Data on the ability of bacteria to produce the IAA growth hormone were regressed with root length.

3 Results

The results of research on the ability of microbes to produce the IAA growth hormone and nitrogen fixation in crushing phosphate are presented in Tab. 1. The ability of bacteria from the goat rumen to produce extracellular enzymes (cellulase, amylase, and protease enzymes) is presented in Tab. 2. The ability of microbial isolates from goat rumen to increase the length of sprout roots is presented in Fig. 2.

<table>
<thead>
<tr>
<th>Isolate Codes</th>
<th>IAA Synthesis (ppm)</th>
<th>Nitrogen Fixation</th>
<th>Phosphate Solubility (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P102</td>
<td>55.00</td>
<td>++</td>
<td>1.10</td>
</tr>
<tr>
<td>P103</td>
<td>26.89</td>
<td>++</td>
<td>1.14</td>
</tr>
<tr>
<td>P104</td>
<td>30.00</td>
<td>+</td>
<td>1.11</td>
</tr>
<tr>
<td>P105</td>
<td>30.33</td>
<td>+++</td>
<td>1.10</td>
</tr>
<tr>
<td>P106</td>
<td>35.44</td>
<td>+++</td>
<td>1.10</td>
</tr>
<tr>
<td>P107</td>
<td>36.00</td>
<td>+++</td>
<td>1.15</td>
</tr>
<tr>
<td>P201</td>
<td>29.56</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>P202</td>
<td>51.78</td>
<td>++</td>
<td>-</td>
</tr>
<tr>
<td>P203</td>
<td>37.89</td>
<td>++</td>
<td>-</td>
</tr>
<tr>
<td>P204</td>
<td>34.56</td>
<td>+++</td>
<td>-</td>
</tr>
<tr>
<td>P205</td>
<td>29.00</td>
<td>+++</td>
<td>1.25</td>
</tr>
<tr>
<td>P206</td>
<td>207.67</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>P207</td>
<td>34.22</td>
<td>++</td>
<td>1.63</td>
</tr>
<tr>
<td>P208</td>
<td>31.78</td>
<td>+++</td>
<td>-</td>
</tr>
</tbody>
</table>

Notes: + (somewhat cloudy), ++ (cloudy), +++ (very cloudy)

Fig. 2 Influence of bacteria from goat rumen on soybean root length (Developed by the authors)

The research results in Tab. 1 show that microbes from the goat rumen are reported to be able to synthesize IAA in the range of 29.00–207.67 ppm. The highest ability of bacteria from the goat rumen to synthesize the IAA hormone was obtained in isolate P206 at 207.67 ppm and the lowest was in isolate P103 at 26.89 ppm. The research results in Tab. 1 show that bacterial isolates from the goat rumen were able to fix nitrogen, with the highest ability obtained in isolates P105, P106, P107, P204, P205, and P208.
The research results in Tab. 2 show that there were 13 bacterial isolates from goat rumen that were capable of producing cellulase enzymes. The ability of bacteria from goat rumen to produce cellulase enzymes was the highest in isolate P106 at 5.14 cm and the lowest in isolate P105 at 1.68 cm. The research results in Tab. 2 also show that bacteria from goat rumen are capable of producing amylase enzymes. The highest ability was determined in isolates P104 and P202 at 4.00 cm, and the lowest ability was found in isolate P107 at 1.65 cm. Meanwhile, the ability of bacteria from goat rumen to produce protease enzymes was determined by 13 isolates, with the highest ability in isolate P103 at 5.00 cm and the lowest in isolate P204 at 1.40 cm.

The research results in Fig. 2 show that the highest microbial isolate from the goat rumen for the highest root length of soybean seeds was obtained from isolate P206 at 18.04 cm, which was not significantly different from other isolates but was significantly different from isolates P103 and P107, especially the control at 9.68 cm.

4 Discussion

The results of the research show that bacteria from the goat rumen can synthesize the IAA hormone, fix nitrogen, dissolve phosphate, produce cellulase, protease, and amylase enzymes, and increase the length of soybean seed sprout roots. This agrees with previous studies that reported that some microbes can produce the IAA hormone [20,21], nitrogen fixation [22–24], and phosphate soluble [25,26]. It was further reported that several groups of bacteria are capable of producing cellulase enzymes [27–29], protease enzymes [30], and amylase enzymes [31,32].

The IAA hormone produced by microbes is reported to be able to increase plant growth [33,34]. Apart from that, microbes are also able to fix nitrogen and dissolve phosphate, which has an important role in the nutrient cycle, which increases plant growth and yield [35–37]. Apart from being able to increase plant growth and yield, microbes from the goat rumen are also reported to be able to produce enzymes that play a role in increasing plant resistance to plant diseases [38–40]. This agrees with previous research reports that microbes that produce cellulase, protease, and amylase enzymes can act as biological control agents [39,41].

Relevant research reports that many bacterial isolates are able to control plant diseases both in vitro and in vivo. Bacteria are reported to have the ability to produce HCN compounds [42], and extracellular enzymes [15,43] and can produce salicylic acid [44], which plays a role in controlling plant diseases.

Microbes that produce amylase, cellulase, and protease enzymes can degrade cell walls, which are the main constituents of the cell walls of several types of pathogens that cause disease in plants [45,46]. The results of research on the use of enzymes from microbes have proven effective in controlling pathogens [19,47,48].

Apart from being able to increase plant resistance, bacteria from goat rumen can also stimulate the growth of soybean seed sprout roots. The research results in Fig. 2 show that bacteria from goat rumen are able to increase soybean sprout root length. This agrees with previous research, which reported that bacteria play a role in increasing seed germination [4,49] and root length of sprouts [44,50,51]. It was further reported that bacteria can increase plant growth and yield [21,52,53]. The ability of bacteria from the goat's rumen to increase the root length of soybean seed sprouts is due to the ability of the bacteria from the goat's rumen to produce the IAA hormone (Tab. 1). The IAA hormone is an exogenous hormone that can stimulate root length growth in plants [84]. This agrees with previous research reports that bacteria producing the IAA hormone can increase plant root length [55,56].

5 Conclusions

Bacteria from the goat rumen can produce the IAA hormone, dissolve phosphate, fix nitrogen, produce cellulase, protease, and amylase enzymes, and lengthen the sprout roots compared with those without treatment (control). These goat rumen bacteria are different from those in previous research that focused only on the use of goat rumen as a liquid fertilizer and its role as a biodecomposer. This research has an impact on increasing plant growth, cycles of nutrients, especially the N and P elements, and biological control agents. This research is limited to laboratory-scale testing. Therefore, these findings still require direct validation on a field scale. However, this research can increase plant growth, crop yields, and plant resilience and support sustainable agricultural development.
Acknowledgment

We thank the Directorate General of Vocational Education of the Ministry of Education, Culture, Research, and Technology for funding this research through the 2023 Beginner Matching Fund Grant and the Sentosa Kalimantan Jaya Company for facilitating this activity.

References


[1] GULNAZ Y, FATHIMA PS, DENESH G R

[2] HAERANI N, SYAM’UN E, RASYID B

的分离和表征。生物多样性，2021，22(5)，2497–2503。
[3] 唐阿，HARUNA A O，MAJID N M，等。恢复热带森林土壤中纤维素分解、固氮、解磷细菌的潜在PGPR特性。微生物，2020，8(3)，442。
[7] SONIA A V，SETIAWATI T C，等。槟榔根际内生根际细菌溶解磷酸盐、固氮、解磷细菌的潜在PGPR特性。国际航空协会杂志，2020，23(3)，240–247。
[8] MITRA M，SINGH R，GHISSING U 等人。从钙质土壤中生长的本地植物的根际中分离和表征解磷细菌。国际植物学研究杂志，2022，260，127021。
[9] MURALI M，SINGH SB，GOWTHAM HG 等。通过抗氧化防御系统产生PGPR-解淀粉芽孢杆菌的ACC脱氨酶诱导狼尾草的耐旱性。微生物研究，2021，253，126891。
[10] BUKHAT S，IMRAN A，JAVAID S，等。植物与微生物世界的通讯：探索PGPR介导的防御信号的调控网络。微生物研究，2020，238，126486。
[12] ABBAS Z，AMIR ZIA M，ALI S，等。植物根际促生菌、解磷菌和化肥对玉米生长的综合作用。国际农业与作物科学杂志，2013，6(13)，913-921。
[14] CHANDRAN H，MEENA M，SWAPNIL P。促进植物生长的根际细菌作为可持续农业的绿色替代品。可持续发展，2021，13(19)，10986。
[15] BASU A，PRASAD P，DAS S N，等。作为绿色生物接种剂的植物根际促生长细菌（PGPR）：最新发展、限制和前景。可持续发展，2021，13(3)，1140。
[16] SINGH R，GOODWIN S B。探索玉米微生物组：对当前知识、技术和未来方向的详细回顾。植物前沿TM，2022，2(3)，158–175。
[17] GROVER M，BODHANKAR S，SHARMA A，等。PGPR介导的根性状改变：实现可持续作物生产的途径。可持续粮食系统前沿，2021，4，618230。
[18] KARPAGAM T，NAGALAKSHMI P K。农业土壤中解磷微生物的分离和表征。国际当代微生物学和应用科学杂志，2014，3(3)，601–614。
[19] IRSYADAH N，SANTOSA S，等。科布门受粉蚧(边缘副球菌)攻击的木瓜种植园土壤中淀粉分解细菌和蛋白水解细菌的分离和表征。兰特拉生物：生物科技期刊，2024，13(1)，86-92。
[20] LAREKENG SH，GUSMIATY，ACHMAD
F. 群落林分根际细菌分离株中抗菌协同作用的产生。眼压会议系列：地球与环境科学，2020, 575, 012022.


[22] YONEYAMA T, TERAKADO-TONOOKA J, MINAMISAWA K。与土壤种植的甘蔗、甘薯和水稻相关的细菌固氮系统的探索：综述和综合。土壤科学与植物营养，2017, 63(6), 578–590。

[23] AGUSTIYANI D, DEWI T K, LAILI N, 等。探索来自不同植物生态系统的促进植物生长的根际细菌候选物的生物肥料潜力。生物多样性，2021, 22(5), 2691–2698。


[27] GUDER D G, KRISHNA M S R。绵羊瘤胃中潜在纤维素降解细菌的分离和表征。纯粹与应用微生物学杂志，2019, 13(3), 1831-1839。

[28] POLY NY, MAMTAZ S, KHAN M M H 等人。牛瘤胃液中纤维素分解细菌的分离、记录和生化特征。先进生物技术和实验治疗学杂志，2022, 5(2), 433–444。

[29] WIJONARKO G, SITORESMI I, PURBOWATI M 等。使用山羊瘤胃液中的纤维素酶进行纤维素水解的酶动力学。印度尼西亚食品技术杂志，2022, 1(1), 46–58。


[31] ELAMARY R, SALEM W M。优化和纯化土壤细菌中的细胞外淀粉酶以抑制临床生物膜形成细菌。同行评议杂志，2020, 8, e10288。

[32] 沉杰, 郑丽, 陈旭, 等。饲喂不同瘤胃可降解淀粉的奶山羊瘤胃微生物和碳水化合物活性酶的宏基因组分析。微生物学前沿，2020, 11, 1003。

[33] DOS SANTOS R M, DIAZ PA E, LOBO L L B 等。促进植物生长的根际细菌在玉米和甘蔗中的用途: 特征和应用。可持续粮食系统前沿，2020, 4, 136。

[34] BACKER R, ROKEM J S, ILANGUMARAN G 等。促进植物生长的根际细菌: 可持续农业生物刺激剂商业化的背景、作用机制和路线图。植物科学前沿，2018, 9, 1473。


[36] OLEŃSKA E, MAŁEK W, WÓJCIK M。促进植物生长的根际细菌在挑战性条件下改善植物生长和健康的有益特征：系统评价。全球环境科学，2020, 743, 140682。

[37] FADIL M, YANTI Y, KHAIRUL U.
水稻根际放线菌作为糯白叶枯病菌生物防治剂的筛选。米曲霉病原体引起细菌性叶枯病。《农业杂志》，2023年，10(1)，1–15。

[39] 法蒂玛一世、哈基姆S、伊姆兰A等。探索从天然抑制性土壤中分离出的多方面PGPR对糯白叶枯病菌致病因子的生物防治及促生长潜力。微生物研究，2022，260，127015。

[40] BATOOLO T、ALI S、SELEMAN M F等人。促进植物生长的根际细菌通过抑制氧化应激和抗氧化酶活性来缓解马铃薯的干旱应激。科学报告，2020年，10，16975。

[41] AZEEM S、AGHA S I、JAMIL N等人。针对植物病原真菌的广谱生物防治剂的表征和存活。阿根廷微生物学杂志，2022，54(3)，233–242。

[42] KHAN N、ALI S、SHAHID M A等人。深入了解根、根际和根际细菌之间的相互作用, 以改善植物生长和对非生物胁迫的耐受性: 综述。细胞，2021，10(6)，1551。

[43] CARLOS M H J、STEFANI P V Y、JANETTE AM等人。评估ACC脱氨酶和国际航空协会生产中重金属对植物促生长细菌的影响。微生物研究，2016，188-189，53-61。

[44] EL-MERGAWI R A、ABD EL-WAHED M S A。外源水杨酸或吲哚乙酸对其内源水平，发芽和玉米生长的影响。国家研究中心公报，2020年，44，167。

[45] KÖHL J、KOLNAAR R、RAVENSBERG W J。微生物生物防治剂对抗植物病害的作用模式: 超越功效的相关性。植物科学前沿，2019，10，845。

[46] RORI CA、KANDOU F E F、TANGAPO AM。植物内生细菌胞外酶活性对红树林白骨壤码头。《期刊简介》，2020年，11(2)，48–55。

[47] SINGH N、SINGH D。植物生长促进细菌对种子萌发、幼苗活力和生长的影响紫叶葫芦(莫利纳)斯坦德尔。国际当代微生物学和应用科学杂志，2020，9(8)，1161–1168。

[48] MADE GUYASA I、SADIMA NTARA GR、KHAERUNI A等人。玉米产量和磷利用效率对与植物促生长细菌相关的磷速率的响应。环境科学前沿，2020，8，40。

[49] LESTARI S D、KUSUMANINGRUM NA、MOELJANI I R。卡维斯塔幼苗(酸柠檬)对PGPR管理的生长反应（植物生长促进根际细菌）。胚芽：贝尔卡拉伊尔米亚农业技术公司，2020，8(2)，93–100。

[50] DEMEULENAERE M J F、BEECKMAN T。植物发育过程中生长素与细胞周期之间的相互作用。见：ZAŽÍMALOVÁ E、PETRÁŠEK
J. BENKOVA E. (编) 生长素及其在植物发育中的作用。维也纳：施普林格，2014：119-141。

ASTRIANI M, ZUBAIDAH S, ABADI A L 等。从印度尼西亚爪哇东爪哇瘤胃本土微生物（国际海事组织）中分离和鉴定解磷细菌作为生态友好型生物肥料。马来西亚微生物学杂志，2020，16(4)，253–262。