氏　　名	MUHAMMAD　SHAHBAZ　AKHTAR
授与した学位	博　士
専攻分野の名称	学　術
学位授与番号	博甲第３６７１号
学位授与の日付	平成２０年　３月２５日
学位授与の要件	環境学研究科社会基盤環境学専攻 （学位規則第５条第１項該当）
学位論文の題目	Phosphorus Starvation Induced Root Mediated Solublization of Sparingly Soluble P-Sources and Analysis of P-use Efficiency by *Brassica* Cultivars under P-stress Environment （アブラナ品種によるリン欠乏が誘発する根を介した難溶性リン酸塩源の可溶化状態およびリン利用効率）
論文審査委員	教授　足立　忠司　　教授　沖　　陽子　　准教授　村田　芳行

学位論文内容の要旨

Nevertheless, *Brassica*'s importance in edible oil, bio-diesel, Brassiodol, livestock feed, raw material for bio-composites, plastics, high value lubricants, condiments and production of derived compounds (antioxidants, vitamins, anti-carcinogenic etc.) cannot be overemphasized, but notorious low availability of phosphorus (P) have prominent effect on limiting crop production in general, and oil contents and seed yield of many oil seed crops in particular. P-starvation is more critical in highly weathered soils of tropics and subtropics, as well as alkaline calcareous soils of Mediterranean basin limiting crop production > 30% of world's arable land, and global P-reserves are being depleted, with half depletion predicted to occur between 2040 and 2060. To acclimate under P-stress environment, P-starvation induced (PSI) adaptations can be divided into 4 parts i.e., morphological, biochemical, physiological, and molecular adaptive mechanisms. To elucidate PSI differential morphological and biochemical adaptative traits at inter- and intra-specific level in nonmycotrophic '*Brassica*', we collected diverse *Brassica* genome (*B. napus, B. compestris, B. Juncea & B. carinata*) from Nuclear Institute of Biology and Genetic Engineering (NIBGE), Ayub Agricultural Research Institute (ARRI), and Nuclear Institute of Agriculture and Biology (NIAB), Pakistan. Jordan rock phosphate (RP) [analyzed and categorized as finely ground (0.15 mm) contained 13.6 % total P, 4.5 % citrate-soluble (2 % citric acid) P and no water soluble P] was imported from Jordan. Rock-P and $Ca_3(PO_4)_2$ (TCP) was used to induce deficiently buffered P-stress environment, and $NH_4H_2PO_4$ or KH_2PO_4 were used for various stress (low) and high P-levels along with other essential macro and micronutrients in various culture media (hydroponics, sand, soil, pot, split pot, agar culture with different pH indicators such as bromocresol purple, and rhizobox cropping techniques, etc.) in climatically controlled cultivation chambers, rooms and glass house etc., and data set has been established systematically.

Holistic extensive serial experimental screening and categorization in terms of P-acquisition (relative P-solublization, absorption, uptake efficiency, uptake rates and kinetics; V_{max}, K_m, C_{min} etc.), translocation and assimilation (P-transport, partitioning, recycling, remobilization and re-translocation from metabolically inactive sites to active sites), and internal utilization (relative P-utilization efficiency, P-efficiency ratios, P-stress factor, P-Zn interactions and use efficiencies, N-forms and Ca-uptake effects, and comparative specific P-utilization rates) of collected genome subjected to varying levels and sources of P was carried out at inter- and intra-specific genetic diversity level. Numerous growth and growth related parameters [Biomass assay (shoot, root and total dry matter, root-shoot ratios, leaf area , absolute and relative growth rates etc.), modification of root architecture under P-stress (remodeling and altered lateral root anatomy, topological index, lateral roots and root hair length etc.), genetic parameters (variability, heritability, co-heritability, relative yield and yield contributing characters, genetic advance and expected genetic advance), and correlation matrix (path analyses, simple correlation analysis, and genotypic and phenotypic correlation coefficients under deficiently buffered P-stress environment] was investigated to dissect the various parts of PSI morphological and biochemical adaptive mechanisms. Available genetic pool was categorized by using ordination plots and path cladograms between various growth parameters and classified as Efficient/Superior; Inefficient/Inferior; P-tolerant; P-sensitive; Efficient and Responsive (ER); Non-efficient but Responsive (NER); Efficient but non-responsive (ENR); Non-efficient and non-responsive (NENR) etc. P-starvation induced root mediated rhizosphere pH changes in relative solublization, scavenging and acquisition of sparingly soluble P-sources (e.g. RP and TCP etc.) and carboxylates (organic acids; citrate, fumarate, succinate, and malate: amount, type and time course effect etc.) exudation and H^+-efflux among efficient and non-efficient genome was also investigated and categorized into different classes according to their ability of rhizosphere acidification and to thrive under P-stress environment. Tested cultivars showed inter- & intra-specific genetic diversity in accessing, mobilization, acquisition and utilization of Pi from sparingly soluble P forms. An arrange marriage of plant traits can explain access to different forms of sparingly soluble P, and in addition to altered lateral root topology and enhanced P-uptake and PUE, enhanced Ca-uptake, H^+-efflux and carboxylates extrusion were key factors in Pi-scavenging from extra cellular sparingly soluble P-sources & bound soil P forms.

論文審査結果の要旨

パキスタンでは，食用油の75％を輸入に頼っている。この状況を打開するためには，アブラナ科のような油を生成できる植物の生産性を確保する必要があるが，土壌中の無機態リンの不足がその生産性を阻害している。一方，世界的に見ても，今世紀半ばにはリン欠乏時代が予測されている。このような背景を踏まえ，申請者は，アブラナ科植物を供試指標に，土壌（溶液）中のリン挙動の解明を行っている。得られた結果は次のように要約される。

まず，アブラナ科アブラナ属ナタネ10品種の水耕栽培試験により，リン欠乏のストレスに対する生育反応を検討し，シュートや根のバイオマスは，シュートにおけるリン吸収やリン利用特性との相関が高く，効果的にリンが利用できる品種はリン欠乏条件下でも，効率よくバイオマスを生産することを明らかにした。また，ナタネ品種を供試してリン欠乏条件下の根部抽出物を分析した結果，能率的な品種は非能率的な品種の２～３倍の有機酸（マレイン酸とシトラス酸）を滲出していることを把握し，さらに，リン源が異なる培地にて検討したところ，リン吸収が高い品種ほど，培地のpHは，根部抽出物により低下していること，高いカルシウム（Ca）吸収能力とCa集積能力がある品種ほど高いバイオマス生産を示すことを明らかにしている。ついで，利用価値の高いナタネ類を供試材料に選定し，リン欠乏条件下におけるリンの吸収や有効性の高い品種の根部の物質代謝の解明や根部におけるリンの挙動と種々のリン源との関係について詳細に検討している。

以上の研究成果は，土壌中のリン欠乏に耐性を持ち，少ないリン酸イオンを的確に植物体内で有効化するメカニズムを明らかにしたものであり，その特性は今後世界的に生ずるリン欠乏時代に，リン酸化学肥料等の施肥量を減少させる持続的な作物生産や土壌中のリン存在の維持管理の活用に大きく寄与するものであると評価でき，博士（学術）の学位を授与するに値すると判定した。