Producing Black Pepper (*Piper nigrum* L. cv. ‘Kuching’) Rootstock in a Deep-Water Culture Hydroponic System

BABIRYE KHADIJAH¹, PATRICIA KING JIE HUNG#¹,² & ONG KIAN HUAT¹

¹Faculty of Agricultural Science and Forestry, Universiti Putra Malaysia, 97000 Bintulu Sarawak, Malaysia; ²Institut Ekosains Borneo, Universiti Putra Malaysia, 97000 Bintulu Sarawak, Malaysia

*Corresponding author: patricia@upm.edu.my

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ABSTRACT

Stem cutting is the common planting material for black pepper (*Piper nigrum* L.) farmers mainly because the method is cheap, easy to obtain, and produces satisfactory number of new plantlets, which are relatively genetically uniform to their parents. However, soil propagation of stem cuttings renders both the stem and developing roots susceptible to soil borne pathogens, ultimately compromising the quality of the plant. Good quality rootstock of the new plant promotes faster, safer, and better black pepper plant establishment. Hydroponic farming thus offers a good platform for producing quality rootstock of the new plants and has gained importance to many farmers due to its flexibility in manipulating plant growth conditions and timely pathogen management, thus safer, healthier, and faster growth. This study investigated the growing media suitable for rootstock growth of *P. nigrum* L. cv. ‘Kuching’ and compared the rooting ability between stem cuttings with adventitious roots at the time of planting and stem cuttings without any root at the time of planting. In a laboratory setting, a total of 210 stem cuttings were hydroponically planted in seven nutrient compositions, with each nutrient composition containing an equal number of stem cuttings with adventitious roots at the time of planting and stem cuttings without any root at the time of planting. Hoagland solution supplemented with 0.005 mM potassium silicate solution (T4) and Hoagland solution supplemented with 2 mM salicylic acid solution (T6) showed faster root initiation whereas T1 (Hoagland solution only) produced the highest increment in root length followed by T6. The least suitable nutrient composition was T5 [T4 + 6 mL of 1 M Ca(NO₃)₂.4H₂O solution]. The total number of roots was highest in plants from stem cuttings which had some adventitious roots at the time of planting, whereas roots in plants from stem cuttings which did not have any root at the time of planting, increased in root length faster than plants with stem cuttings which had adventitious roots at the time of planting.

Keywords: Hoagland solution, potassium silicate, salicylic acid

INTRODUCTION

Popularly known as the ‘king of spices’, black pepper (*Piper nigrum* L.) is a perennial vine belonging to family Piperaceae whose berries are highly valued as spice and medicine (Zhigang et al., 2010; Ahmad et al., 2012; Meghwal & Goswami, 2013). It is widely cultivated in many countries all over the world, including Malaysia (Sivaraman et al., 1999). The cultivars commonly grown in Malaysia include Semenggok Emas, Semenggok Aman, Semenggok Perak and Kuching. Kuching is the traditional cultivar, with high yields, most preferred variety for creamy white pepper production but with the thinnest pericarp and highly prone to major root parasites and diseases for example root-knot nematodes (Megir & Paulus, 2011). Such root parasites severely damage black pepper roots ultimately causing poor development of the plant root stock (Megir & Paulus, 2011) which negatively impacts black pepper yields (Ravindra et al., 2014).

Black pepper is a shade-loving crop and develops physiological disorders once exposed to direct solar radiation, even if the soil moisture conditions are ideal (Vjayakumar et al., 1984; Vjayakumar & Mammen, 1990). It neither tolerates too high nor too low temperatures and the optimum soil temperature for its root growth is 26-28 °C (De Waard & Zeven, 1969; Wahid & Sitepu, 1987). According to Zhigang et al. (2010), temperature has a significant effect on radical length of black pepper seeds during germination. Additionally, evidence that nutrient and water uptake from the roots are affected by the nutrient solution/soil temperature is well documented (Pregitzer & King, 2005; Rachelle et al., 2009; Andreas et al., 2019).

Black pepper requires an optimum supply of
both macronutrients and micronutrients for productive yield (Ann, 2012; Kevin et al., 2018). According to Srinivasan et al. (2007; 2012), the major nutrients required by black pepper are N, P, K, followed by secondary nutrients Ca and Mg. Nerrisa et al. (2018) estimated a three-fold increment in black pepper yields from high yielding cultivars i.e., Kuching, Semenggok Emas, and Semenggok Aman if proper nutritional management is not compromised. To this end, Srinivasan et al. (2012) pinpoints that a clear understanding of black pepper’s nutrient dynamics coupled with timely provision of essential nutrients are key components in achieving sustainable black pepper yields.

Promotion of root development by salicylic acid and silicon fertilisation has been reported in many studies. Salicylic acid (SA) is a phenolic compound that regulates plant growth and development in various aspects, including nutrient uptake, root initiation and growth (Khan et al., 2015; Wani et al., 2016; Pasternak et al., 2019). Plant exposure to exogenous SA promotes development of adventitious, primary and lateral roots in many plants (Yang et al., 2013; Pasternak et al., 2019). In the same vein, improved beneficial effects to plants in response to silicon fertilization is well-documented (Laane, 2018); including its regulatory role in the uptake of other plant nutrients (Ma & Yamaji, 2006; Liang et al., 2007; Al-Wasfy, 2013; Deshmukh et al., 2017).

Because black pepper is both a nutritionally demanding and weather-sensitive crop (Srinivasan et al., 2012), hydroponic farming seems a better cultivation method to produce new plants in overcoming the adverse effects of sudden weather, soil nutrition and pH uncertainties that would compromise the new plant’s quality. Hydroponic farming involves cultivation of crops in a soilless medium (Eduardo et al., 2015; De Souza et al., 2018; Wada, 2019), in which the plant’s growth conditions are manipulated in real-time as desired by the farmer (Sambo et al., 2019). It is a positive response towards a friendlier agriculture in comparison with soil-based farming (Islam et al., 2018; Sambo et al., 2019; Wada, 2019) and has gained much attention worldwide, notably in vegetable production (De Souza et al., 2018; Spehia et al., 2018; Sambo et al., 2019). This timely ‘manipulation’ of growth conditions translates into safer, healthier, and faster growth rate. Furthermore, hydroponic cultivation guarantees commencement of the crop production cycle in absence of soil-borne pests and diseases, allows for a more detailed analysis of the whole root system in addition to easier monitoring of root growth which facilitates timely pest management and thus promoting production of good quality rootstock of the new plant (Amalfitano et al., 2017; Pignata et al., 2017; Spehia et al., 2018).

However, one of the most vital aspects of hydroponics is the nutrients’ composition and concentration added to the system (Libia & Fernando, 2012; Valentinuzzi et al., 2015; Lee et al., 2017); any compromise results in poor yield (quality and quantity). As the hydroponic nutrient solution is the sole source of nutrients for the hydroponic plant, it is thus imperative to supply a balanced solution that contains all plant nutrients, in the right balance (Lee et al., 2017; Wada, 2019). In hydroponic systems, plant productivity is closely related with nutrient uptake and pH regulation (Marschner, 1995). Hoagland’s solution (1950) is a standardized nutrient medium that was developed in an attempt to ensure adequate nutrition for a wide variety of hydroponically grown plants experimentally; it provides the minimum parts per million (ppm) needed of each element for healthy plant growth to occur (Zabel et al., 2019). Just like in soil cultivation, it is paramount that temperature of the growing media is maintained within the optimum range in a hydroponic system. Temperature of the root environment significantly impacts root growth and behaviour; high temperatures increase diffusion of dissolved oxygen from the hydroponic system (Graves, 1983).

In the present era where hydroponic farming has gained much importance to many farmers (Libia & Fernando, 2012; De Souza et al., 2018; Sambo et al., 2019), it is paramount that the nutritional requirements of hydroponic black pepper (P. nigrum L.), that can promote optimal growth especially of the root system are established. The present study therefore aimed at developing hydroponic solutions for black pepper (P. nigrum L. cv. ‘Kuching’) and the specific objectives were to establish the i) suitable growing medium for root stock development of hydroponic P. nigrum L. cv. ‘Kuching’; ii) suitable stem cuttings for hydroponic P. nigrum L. cv. ‘Kuching’ by comparing stem cuttings with adventitious roots and stem cuttings without any root at the time of planting.
MATERIALS AND METHODS

Freshly harvested healthy black pepper (P. nigrum L. cv. ‘Kuching’) stem cuttings (with no symptoms of mineral deficiency, disease or insect damage) were obtained from the Malaysian Pepper Board. These stem cuttings were harvested during the same period from mother plants which were 2.5 years old, from the same P. nigrum L. cv. ‘Kuching’ farm. Nutrient salts used in the present study include Hoagland’s No. 2 basal salt mixture powder (Sigma-Aldrich, USA), SA (Merck, China), potassium silicate (Sigma-Aldrich, Canada), among others. This study was conducted at the Centre of Excellence, Plant Health and Diagnostic Laboratory, Universiti Putra Malaysia Kampus Bintulu. Black pepper stem cuttings were hydroponically planted in the laboratory (Figure 1) by filling the growing trays (34 cm diameter each) with 10 L of the Nutrient solution (NS), maintaining the electrical conductivity (EC) and pH in ranges of 1.8-2.5 mS/cm and 5.8-6.3, respectively and supplying the NS with dissolved oxygen through powered aeration with air pumps and air stones, employing the deep-water culture method (Figure 2). Each growing tray initially contained two air stones, and a third air stone was later added to each growing tray at week 2 (due to an observed characteristic root browning coinciding with an increase in the total number of roots and root length). The media temperature was maintained at 28 °C. Black pepper cuttings were re-cut slantwise on the lower end with an alcohol-disinfected pruning shear (to avoid contamination), quickly coated with a thin layer of talcum powder containing rooting hormone (Indole Butyric Acid powder- to hasten root initiation and to increase the number of roots produced per cutting) at the cut end, gently rested in meshed cups and supported in an upright position by sponge cubes. The cuttings in meshed cups were submerged into growing trays containing NS, to a depth of 2.5 cm and supported above the growing tray by polystyrene (Figure 1). All growing trays were arranged in a completely randomized design on the laboratory table.

A total of 210 plants were propagated and involved both stem cuttings with adventitious roots (mean length of 2.01cm) and stem cuttings without any root. Stem cuttings with 3-4 nodes were used in this study. The NS, EC and pH were monitored daily, and timely adjustments were made accordingly (if out of the recommended range). Each growing tray was topped up with distilled water every after a 15% NS reduction. Fresh NS was provided to a growing tray, every after the total amount of topped-up water had reached half the original volume of the NS. Plant-response data was collected every after two weeks for a total period of a month and assessed for the following growth variables; (i) total number of roots and (ii) root length. Root length was measured using a measuring tape expressed in centimetres. A cutting was considered rooted when it produced at least 5 mm length of the root.

This study tested seven media compositions (Table 1) with 30 black pepper plants/stem cuttings per treatment. Hoagland solution (T1) was used as a baseline formulation. Data was log transformed and analysed using the SAS software, version 9.4. Mean separations were performed through the Duncan’s multiple range test, with reference to 0.05 probability level.

RESULTS AND DISCUSSION

Feasibility of the Hydroponic Solutions on Plant Performance

Among the treatment compositions investigated, P. nigrum L. cv. ‘Kuching’ cuttings cultivated in T4 (Hoagland solution supplemented with 0.005 mM potassium silicate solution) and T6 (Hoagland solution supplemented with 2 mM SA solution) produced the highest total number of roots at week 2 (Table 2). However, the performance of hydroponic solutions T1 (Hoagland solution), T2 (Hoagland solution supplemented with 1 M KNO₃) and T7 [Hoagland solution supplemented with 6 mL of 1 M Ca(NO₃)₂.4H₂O and 2 mM SA solution] can also be considered as satisfactory as they produced similar number of roots when reached week 4. T3 [Hoagland solution supplemented with 1 M Ca(NO₃)₂.4H₂O] underperformed as compared to the other treatments, as it presented the fewest total number of roots at the end of the experiment.

Plants cultivated in T4 and T6 produced the longest increment of roots length when reached week 2 (Figure 3). However, towards week 4, Hoagland solution (T1) outperformed other treatments. T5 [Hoagland solution supplemented with 1 M Ca(NO₃)₂.4H₂O and 0.005 mM potassium silicate solution] had the poorest performance in root extension and presented the shortest roots at the end of the experiment. The performance of Hoagland solution (T1) was satisfying in the present study.
Table 1. Nutrient composition for the different treatments

| Treatment | Composition                                                                 |
|-----------|-----------------------------------------------------------------------------|
| T1        | Hoagland solution                                                           |
| T2        | T1 + 6 mL of 1 M KNO₃ in each liter of Hoagland solution                    |
| T3        | T1 + 6 mL of 1 M Ca(NO₃)₂.4H₂O in each liter of Hoagland solution           |
| T4        | T1 + 0.005 mM potassium silicate in each liter of Hoagland solution         |
| T5        | T3 + 0.005 mM potassium silicate in each liter of Hoagland solution         |
| T6        | T1 + 2 mM SA solution in each liter of Hoagland solution                    |
| T7        | T3 + 2 mM SA solution in each liter of Hoagland solution                    |

Table 2. Total number of roots of experimental plants from week 0-week 4

| Treatment composition | Total number of roots after log transformation |
|-----------------------|-----------------------------------------------|
|                       | Week 0 | Week 2 | Week 4       |
| T1                    | 3.30 ± 1.15ᵇ₂ | 3.69 ± 0.03ᵇ₂ | 4.69 ± 1.02ᵃ₁ |
| T2                    | 3.37 ± 1.14ᵇ₂ | 3.47 ± 0.03ᵇ₂ | 4.43 ± 1.01ᵃ⁻¹ |
| T3                    | 2.94 ± 0.99ᵃ⁻² | 3.47 ± 0.03ᵇ₂ | 4.02 ± 0.09ᵇ⁻¹ |
| T4                    | 3.43 ± 1.10ᵃ⁻² | 4.38 ± 1.09ᵃ⁻¹ | 4.64 ± 1.07ᵃ⁻¹ |
| T5                    | 2.20 ± 0.01ᵇ³ | 3.40 ± 0.00ᵇ₂ | 4.28 ± 0.68ᵇ⁻¹ |
| T6                    | 3.09 ± 1.13ᵃ⁻² | 4.62 ± 0.10ᵃ⁻¹ | 4.90 ± 1.00ᵃ⁻¹ |
| T7                    | 3.00 ± 1.00ᵃ⁻³ | 3.87 ± 0.04ᵇ⁻² | 4.49 ± 1.02ᵃ⁻¹ |
Feasibility of the Presence or Absence of Adventitious Roots on the Planting Material

A growth comparison was made between plants whose stem cuttings had some adventitious roots at the time of planting (R) with similar plants whose stem cuttings did not have any root at the time of planting (U). At week 4, the total number of roots in plants from R cuttings were higher than those plants from U cuttings (Table 3).

From the result of the experiment (Table 4), U cuttings had faster increment in root number than R cuttings from week 0 to week 2. In the subsequent fortnight, the increment slowed down and the advantage of U cuttings disappeared in all treatments. However, in terms of root length (Table 5), U cuttings had significant better increment than R cuttings in all treatments.

One of the most vital aspects of hydroponics is the nutrients’ composition and concentration added to the system and its compromise results into poor growth (Libia & Fernando, 2012; Valentiniuzzi et al., 2015; Lee et al., 2017). Based on the results obtained, hydroponic solutions T6 (Hoagland solution supplemented with 2 Mm SA solution) and Hoagland solution supplemented with 0.005 mM potassium silicate solution (T4) showed faster root initiation and extension for P. nigrum L. plants produced using a deep-water culture technique. Better root system is essential for black pepper as it would enhance nutrient uptake and subsequently promote growth. As noted by previous research, optimising the supply of both macronutrients and micronutrients increases growth plus the productive yield of black pepper (Ann, 2012; Kevin et al., 2018).

Salicylic acid is a phenolic compound that regulates plant growth and development in various aspects, including nutrient uptake, root initiation and growth (Khan et al., 2015; Wani et al., 2016; Pasternak et al., 2019). Evidence that exogenous SA promotes root initiation in different crops especially at low concentrations is well-documented (Khan et al., 2015; Wani et al., 2016; Pasternak et al., 2019). Exogenous SA application at different doses promotes development of adventitious, primary and lateral roots in many plants including pea (Pisum sativum) (Yang et al., 2013; Pasternak et al., 2019). In their analysis of the effect of SA on Arabidopsis thaliana root development, Pasternak et al. (2019) observed that at low concentrations (below 50 μM), exogenous SA regulated root development; it both promoted growth of well-developed adventitious roots and altered architecture of the root apical meristem. However, the threshold between low and high exogenous SA concentrations depends on the plant species in question and the method of treatment i.e., foliar spraying, soil drenching and as a hydroponic
Table 3. Comparison of the total number of roots between plants whose stem cuttings had some adventitious roots at the time of planting and plants whose stem cuttings did not have any root at the time of planting

| Weeks after planting | T1 | T2 | T3 | T4 | T5 | T6 | T7 |
|----------------------|----|----|----|----|----|----|----|
| Week 0              | R  | 3.33 ± 0.30<sup>b</sup> | 3.40 ± 0.26<sup>b</sup> | 2.30 ± 0.18<sup>b</sup> | 3.47 ± 0.21<sup>b</sup> | 2.30 ± 0.16<sup>b</sup> | 3.13 ± 0.24<sup>b</sup> | 3.04 ± 0.22<sup>b</sup> |
|                      | U  | 0.00 ± 0.00<sup>b</sup> | 0.00 ± 0.00<sup>b</sup> | 0.00 ± 0.00<sup>b</sup> | 0.00 ± 0.00<sup>b</sup> | 0.00 ± 0.00<sup>b</sup> | 0.00 ± 0.00<sup>b</sup> | 0.00 ± 0.00<sup>b</sup> |
| Week 2              | R  | 3.99 ± 0.30<sup>b</sup> | 4.04 ± 0.31<sup>b</sup> | 3.37 ± 0.21<sup>b</sup> | 4.13 ± 0.32<sup>b</sup> | 3.64 ± 0.20<sup>b</sup> | 4.26 ± 0.30<sup>b</sup> | 3.09 ± 0.20<sup>b</sup> |
|                      | U  | 2.08 ± 0.11<sup>b</sup> | 2.64 ± 0.07<sup>b</sup> | 2.40 ± 0.13<sup>b</sup> | 2.30 ± 0.11<sup>b</sup> | 2.20 ± 0.10<sup>b</sup> | 3.00 ± 0.21<sup>b</sup> | 2.56 ± 0.10<sup>b</sup> |
| Week 4              | R  | 4.72 ± 0.37<sup>a</sup> | 4.65 ± 0.15<sup>a</sup> | 4.02 ± 0.33<sup>a</sup> | 4.57 ± 0.32<sup>a</sup> | 3.99 ± 0.21<sup>a</sup> | 4.73 ± 0.30<sup>a</sup> | 4.14 ± 0.31<sup>a</sup> |
|                      | U  | 2.71 ± 0.17<sup>b</sup> | 3.04 ± 0.23<sup>b</sup> | 2.64 ± 0.11<sup>b</sup> | 2.83 ± 0.10<sup>b</sup> | 2.08 ± 0.11<sup>b</sup> | 3.53 ± 0.20<sup>b</sup> | 2.56 ± 0.10<sup>b</sup> |

Means with the same superscript (a, b) letter in the same treatment and week were not significantly different at P ≤ 0.05 using Duncan’s Multiple Range Test.
R= Plants from stem cuttings which had some adventitious roots at the time of planting
U= Plants from stem cuttings which did not have any root at the time of planting

Table 4. Comparison of the increment in total number of roots between plants whose stem cuttings had some adventitious roots at the time of planting and plants whose stem cuttings did not have any root at the time of planting across different treatments

| Weeks after planting | T1 | T2 | T3 | T4 | T5 | T6 | T7 |
|----------------------|----|----|----|----|----|----|----|
| Week 0-2            | R  | 0.66 ± 0.00<sup>b</sup> | 0.64 ± 0.71<sup>b</sup> | 1.07 ± 0.03<sup>b</sup> | 0.66 ± 0.29<sup>b</sup> | 1.34 ± 0.09<sup>b</sup> | 1.13 ± 0.56<sup>b</sup> | 0.05 ± 0.11<sup>b</sup> |
|                      | U  | 2.08 ± 0.11<sup>a</sup> | 2.64 ± 0.07<sup>a</sup> | 2.40 ± 0.13<sup>a</sup> | 2.30 ± 0.11<sup>a</sup> | 2.20 ± 0.10<sup>a</sup> | 3.00 ± 0.21<sup>a</sup> | 2.56 ± 0.10<sup>a</sup> |
| Week 2-4            | R  | 0.73 ± 0.04<sup>a</sup> | 0.61 ± 0.43<sup>a</sup> | 0.65 ± 0.12<sup>a</sup> | 0.44 ± 0.00<sup>a</sup> | 0.35 ± 0.02<sup>a</sup> | 0.47 ± 0.00<sup>a</sup> | 1.05 ± 0.37<sup>a</sup> |
|                      | U  | 0.63 ± 0.20<sup>a</sup> | 0.40 ± 0.35<sup>a</sup> | 0.24 ± 0.07<sup>a</sup> | 0.53 ± 0.01<sup>a</sup> | 0.00 ± 0.00<sup>a</sup> | 0.53 ± 0.03<sup>a</sup> | 0.00 ± 0.00<sup>a</sup> |

Means with the same superscript (a, b) letter in the same treatment and week were not significantly different at P ≤ 0.05 using Duncan’s Multiple Range Test.
R= Plants from stem cuttings which had some adventitious roots at the time of planting
U= Plants from stem cuttings which did not have any root at the time of planting

Table 5: Comparison of the increment in root length between plants whose stem cuttings had some adventitious roots at the time of planting and plants whose stem cuttings did not have any root at the time of planting

| Weeks after planting | T1 | T2 | T3 | T4 | T5 | T6 | T7 |
|----------------------|----|----|----|----|----|----|----|
| Week 0-2            | R  | 0.72 ± 1.03<sup>b</sup> | 0.52 ± 0.81<sup>b</sup> | 0.32 ± 0.19<sup>b</sup> | 0.57 ± 0.21<sup>b</sup> | 0.33 ± 0.63<sup>b</sup> | 0.26 ± 0.60<sup>b</sup> | 0.47 ± 0.74<sup>b</sup> |
|                      | U  | 2.16 ± 0.05<sup>a</sup> | 1.87 ± 1.74<sup>a</sup> | 2.16 ± 0.10<sup>a</sup> | 1.81 ± 1.75<sup>a</sup> | 1.55 ± 1.43<sup>a</sup> | 2.79 ± 0.15<sup>a</sup> | 2.41 ± 0.08<sup>a</sup> |
| Week 2-4            | R  | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.25 ± 0.21<sup>a</sup> | 0.05 ± 0.46<sup>a</sup> | 0.02 ± 0.28<sup>a</sup> | 0.18 ± 0.31<sup>a</sup> | 0.04 ± 0.02<sup>a</sup> |
|                      | U  | 0.82 ± 0.17<sup>a</sup> | 0.84 ± 0.07<sup>a</sup> | 0.82 ± 0.13<sup>a</sup> | 0.85 ± 0.11<sup>a</sup> | 0.63 ± 0.19<sup>a</sup> | 0.33 ± 0.25<sup>a</sup> | 1.28 ± 1.17<sup>a</sup> |

Means with the same superscript (a, b) letter in the same treatment and week were not significantly different at P ≤ 0.05 using Duncan’s Multiple Range Test.
R= Plants from stem cuttings which had some adventitious roots at the time of planting
U= Plants from stem cuttings which did not have any root at the time of planting
culture medium (Pasternak et al., 2019). Our findings showed that a concentration of 2 mM SA (T6) would promote faster root initiation and extension of *P. nigrum* L. cv. ‘Kuching’. The promotion of root initiation and extension by exogenous SA could be a result of induced auxin synthesis. According to Ludwig-Müller et al. (2005) and Pasternak et al. (2019), initiation and development of adventitious roots is induced by high cellular auxin synthesis at the root tip by SA. The above findings support current observations that addition of 2 mM SA in T6 hydroponic solution promoted faster root initiation and extension.

*P. nigrum* L. cuttings cultivated in Hoagland solution supplemented with 0.005 mM potassium silicate solution (T4) also showed faster root initiation and extension in the present study. Although silicon (Si) is not considered an essential nutrient for plants, improved beneficial effects to plants in response to Si fertilization is well-documented (Laane, 2018), including a regulatory role in the uptake of other plant nutrients plus improved hydraulic conductance (Ma & Yamaji, 2006; Liang et al., 2007; Deshmukh et al., 2017). For example, applications of 0.05%, 0.1% and 0.2% potassium silicate increased nutrient uptake of N, P, K and Mg in sapkota date palms (Al-wasfy, 2013). Hence, enhanced nutrient absorption might have contributed to the fast root initiation and extension by the black pepper cuttings in Hoagland solution supplemented with 0.005 mM potassium silicate solution (T4).

Hoagland solution is a standard plant medium which supplies all the essential plant nutrients in minimum quantities for healthy plant growth (Hoagland & Arnon, 1938). Over the years, Hoagland solution has been commonly used as a baseline for soilless plant cultivation (Zabel et al., 2019). Based on the results of this study, Hoagland solution (T1) promoted the highest root extension. However, Hoagland solution had to be supplemented with 2 mM SA solution (T6) or 0.005 mM potassium silicate solution (T4) for root initiation to be fast.

The fewest number of roots and shortest root length observed in Hoagland solution supplemented with 6 mL of 1 M Ca(NO₃)₂·4H₂O (T3) and 0.005 mM potassium silicate solution (T5), respectively, which were observed in the present study could have been caused by the common nutrient salt, Ca(NO₃)₂·4H₂O. Although it is a vital nutrient for plant growth, calcium is reactive towards sulphate when in concentrated liquids, and forms calcium sulphate or gypsum, which precipitates out of solution. Moreover, Zhao et al. (2008) reported that sulphur application increased the root number of soybean. Therefore, the observed poor root growth of hydroponic *P. nigrum* L. in T3 and T5 could have been a result of calcium-induced deficiencies of sulfur as high lightened by Mutters et al. (2010).

Root growth is critical to the survival and establishment of stem cuttings. Newly planted stem cuttings are susceptible to stress if they have limited or no access to a proper water and nutrient balance from the soil, arising from delayed root development or insufficient adventitious root growth. According to Steven (2005), the ability of a new plant to overcome planting stress is affected among other factors by its root system size and distribution. Based on the findings of this study, R cuttings showed slight advantage initially in number of roots, but this advantage was eventually lost. The U cuttings outperformed in the increment of root length especially in Hoagland solution supplemented with 6 mL of 1 M Ca(NO₃)₂·4H₂O solution with 2 mM SA solution (T7) than R cuttings (Table 5). Root suberisation may also be a contributing factor to the better root growth in plants whose stem cuttings did not have any root at the time of planting than plants whose stem cuttings had some adventitious roots at the time of planting.

Current findings corroborate with previous results of Steven (2005) which reported that unsuberised roots posed little resistance to nutrient plus water uptake and further root growth. Keeping other factors constant, new/or unsuberised roots facilitate an efficient water and nutrient uptake by the plant whereas older/suberized roots impede efficient nutrient and water uptake by the plant. Hence increased development of new (unsuberised) roots with time in plants from U cuttings, translated into improved nutrient uptake, more roots and lengthier roots initially than in plants from R cuttings. Steven (2005) also observed that newly developed roots have high water and nutrient uptake capability.

**CONCLUSION**

The current study showed that Hoagland solution supplemented with potassium silicate at 0.005 mM (T4), and SA at 2 mM (T6) promoted faster root
growth. Stem cuttings which did not have any root at the time of planting favoured faster increment in root number and extension. The present study assessed root growth of *P. nigrum* L. cv. ‘Kuching’ stem cuttings in a deep-water culture hydroponic system for a total period of 4 weeks. To our knowledge, this is the first study documenting the growth of *P. nigrum* L. in a hydroponic system. We thus recommend that further studies are necessary to (i) establish the performance of these plants after transfer to field conditions (ii) compare with the traditional method of planting material preparation, i.e. sown with sand.

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