การใช้เศษอิฐมอญและถ่านแกลบเป็นวัสดุปลูกที่มีอิทธิพลต่อการเจริญเติบโตและผลผลิตของผักกวางตุ้งฮ่องเต้

Application of Waste Clay Brick and Rice Husk Charcoal as Potting Mixes Influences Pak choi Growth and Yield

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Abstract: The effects of crushed waste brick as the basal material (BM) and proportions of rice husk charcoal (RHC) as a supplement material (SM) of potting mixes for pak choi (*Brassica chinensis*) production were evaluated. The factors included (i) types of BM, i.e., sand and crushed brick, and (ii) proportions of RHC supplementation at the proportion of BM:SM of 1:0, 1:0.5, and 1:1 v/v. Generally, crushed brick decreased pak choi's shoot biomass compared to sand. Supplementing the potting mix with RHC at BM:SM ratio of 1:0.5 v/v rendered an increase in yield compared to 1:0 v/v. Nevertheless, increasing RHC to 1:1 v/v brought about decreases in shoot biomass compared to its lower RHC proportion (1:0.5 v/v).

Keywords: Fired clay brick; Growing media; Nutrient antagonism; Rice husk biochar; Soil conditioner

บทคัดย่อ: ทำการประเมินอิทธิพลของเศษอิฐมอญบดเพื่อเป็นวัสดุปลูกหลัก (basal material, BM) และสัดส่วนของถ่านแกลบ (rice husk charcoal, RHC) เพื่อเป็นวัสดุเสริม (supplement material, SM) สำหรับเป็นวัสดุปลูกในการผลิตผักกวางตุ้งฮ่องเต้ (*Brassica chinensis*) ปัจจัยที่ใช้ในการศึกษาประกอบด้วย (i) ชนิดของ BM คือ ทรายและอิฐมอญบด และ (ii) สัดส่วนของ RHC ซึ่งเป็นวัสดุเสริมโดยมีสัดส่วน BM:SM เป็น 1:0, 1:0.5 และ 1:1 v/v โดยทั่วไปแล้ว อิฐมอญบดลดมวลชีวภาพของส่วนเหนือดินของผักกวางตุ้งเมื่อเปรียบเทียบกับทราย การเสริม RHC ในวัสดุปลูกที่มีสัดส่วน BM:SM เป็น 1:0.5 v/v ทำให้ผลผลิตของผักกวางตุ้งเพิ่มขึ้นเมื่อเปรียบเทียบกับ 1:0 v/v อย่างไรก็ตาม การเพิ่มสัดส่วนของ RHC เป็น 1:1 v/v ทำให้มวลชีวภาพส่วนเหนือดินของผักกวางตุ้งฮ่องเต้ลดลงเมื่อเปรียบเทียบกับวัสดุปลูกที่มีสัดส่วนของ RHC ต่ำกว่า (1:0.5 v/v)

คำสำคัญ: อิฐดินเหนียวเผา, วัสดุปลูกพืช, ภาวะการเป็นปฏิปักษ์ของธาตุอาหาร, ถ่านชีวภาพจากแกลบ, สารปรับปรุงดิน

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Introduction

Environmental degradation nowadays is contributed mainly to the fast economic growth in both manufacturing and agrarian sectors. Re-utilization of industrial wastes and agricultural residues is perceived as strategic ecological safety (Zaman, 2017). From a manufacturing standpoint, broken brick is commonly the construction waste in Thailand (Sujjavanich *et al*., 2014). This brick is originally fabricated from clayey soil combined with sand and a small amount of rice husk ash and heated under extreme temperatures of approximately 1200^{o}C for 2-3 weeks (Chuchaisong and Wongthong, 2009). The brick contains a certain amount of plant nutrients, e.g., K, Ca, Mg, and Fe (Lourenço *et al*., 2010; Sujjavanich *et al*., 2014; Lawanwadeekul *et al*., 2020). Crushing and then employing the waste brick as a potting mix component may be the case for its recycling in crop production. From an agricultural standpoint, rice husk is easily accessible due to its huge availability in many Asian countries, including Thailand (Thambhitaks and Kitchaicharoen, 2021). Pyrolysis of rice husk to charcoal and its use as a potting mix promises to condition the growing media and promote crop growth (Farhan *et al*., 2018). Rice husk charcoal (RHC) has been reported to improve soil fertility and enhance plant growth and yield (Haefele *et al*., 2011; Wang *et al*., 2012). These benefits are due to the fact that RHC poses improving plant nutrient availability (Abrishamkesh *et al*., 2015), increasing and diversifying soil microbes (Singh *et al*., 2018), and neutralizing the pH (Abrishamkesh *et al*., 2015) of the growing media. Nevertheless, the optimum ratio of the mixture of the brick and RHC as a potting mix has not been observed.

Pak choi (*Brassica chinensis*) is a leafy vegetable flavor as a main or side dish worldwide. Proper soil pH for its growth ranges from 6.0 – 6.8 (Ebesu, 2004). Adequate tissue N, P, K, Ca and Mg concentrations are 34, 4.9, 67.9, 19.8, and 4.0 g kg^{-1}, respectively (Huett *et al*., 1997). Commercially, the production of greenhouse vegetables requires a large amount of growing media. Compensation of the expensive commercial media with the low price counterparts, viz waste brick, could cut the production costs. Therefore, the current study aimed at evaluating the effects of the potting mix ratios between crushed brick and RHC on the growth and yield of a vegetable crop.

Materials and Methods

A pot experiment was conducted under a greenhouse condition. The experiment was arranged in a 2x3 factorial in randomized complete block design replicated eight times. Two factors of the potting mix were evaluated, i.e., (i) basal materials including crushed brick in comparison with sand, and (ii) proportions of RHC which was the supplementary material. Mixture ratios of basal to supplementary materials were 1:0, 1:0.5, and 1:1 v/v. Pak choi was used as a test crop.

Waste brick and sand were received from a construction material supplier, while RHC was a commercially available material obtained from an agricultural product store in Sakon Nakhon province. The brick was broken and crushed. Crushed brick, sand, and RHC were sieved to pass to through a 2-mm sieve for further use in the experiment.

Pots (h = 14.0 cm, top d = 20.4 cm, bottom d = 12.8 cm, v = 3,083 cm^3) were filled with the potting mixes in the ratios corresponding to their respective treatments. Each pot was lined with a serving tray. Pak choi was seeded and nursed in a nursery tray for 14 days. A 14-day old seedling chosen for its homogeneity and health was transplanted to a pot. Recommended chemical fertilizers were applied to all pots at the same rates of 110 mg N kg^{-1}, 85 mg P_2O_5 kg^{-1}, and 60 mg K_2O kg^{-1} (Yu *et al*., 2016). A pot was watered to maintain soil moisture at field capacity through the experimental period.

Height and leaf number of pak choi were determined at 20, 27, 34, 41, and 48 days after germination (DAG). At 48 DAG, leaf area was measured using the ImageJ technique (Image Processing and Analysis in Java, National Institutes of Health, Maryland, USA) and leaf area index was calculated from leaf area divided by pot area. At the harvest (48 DAG), the aboveground pak choi was cut and weighed to achieve fresh shoot biomass. The aboveground was subsequently oven-dried at 65°C to gain the constant weight for dry shoot biomass determination.

A two-way analysis of variance based on randomized complete block design in a factorial arrangement was used to evaluate the effects of types of basal material, RHC proportions and their interactions on growth and yield parameters of pak choi. Mean comparisons were assessed using Tukey's honestly significant difference test. The statistically significant differences were appraised at $p \leq 0.05$. The statistical analyses were operated by the SAS version 9.1 (SAS Institute, Cary, NC, USA).

Results

The interaction effects of basal materials (sand and crushed brick) and RHC proportions on height ($p \leq 0.001$) and fresh shoot biomass ($p \leq 0.05$) of pak choi were observed (Table 1). Similarly, the effects of basal material types on height ($p \leq 0.01$) and fresh shoot biomass ($p \leq 0.001$) were found. Meanwhile, the effects of RHC proportions were shown in height ($p \leq 0.001$), leaf number ($p \leq 0.001$), leaf area ($p \leq 0.05$), leaf area index ($p \leq 0.05$), fresh shoot biomass ($p \leq 0.001$) and dry shoot biomass ($p \leq 0.001$).

Table 1 Two-way analysis of variance pertaining to the effects of types of basal material, RHC proportions, and their interactions on growth and yield parameters of pak choi.

Sources of variance	Degree of freedom	*p*-value †					
		Height	Leaf number	Leaf area	Leaf area index	Fresh shoot biomass	Dry shoot biomass
Basal material (BM)	1	**	ns	ns	ns	***	ns
RHC rate	2	***	***	*	*	***	***
BM x RHC rate	2	***	ns	ns	ns	*	ns

* $p \leq 0.05$; ** $p \leq 0.01$; *** $p \leq 0.001$; and ns = not significantly different (*F*-test)

† *p*-values of periodic measurement of growth parameters, i.e., height and leaf number, at the harvest date (48 days after pak choi germination)

At the harvest (48 DAG), the height of pak choi was generally lower in crushed brick treatments (Figure 1B) than in sand treatments (Figure 1A). For both sand and crushed brick, increasing a proportion of RHC from 1:0 to 1:0.5 v/v increased plant height.

Leaf number was not affected by the potting mixes at 48 DAG (Figure 1C and 1D). Leaf area (Figure 1E) and leaf area index (Figure 1F) were not different between sand and crushed brick treatments. Raising an RHC proportion from 1:0 to 1:0.5 v/v rendered greater leaf area and leaf area index in both sand and crushed brick. However, increasing RHC to 1:1 v/v in crushed brick led to lower leaf area and leaf index as compared to its lower RHC proportion.

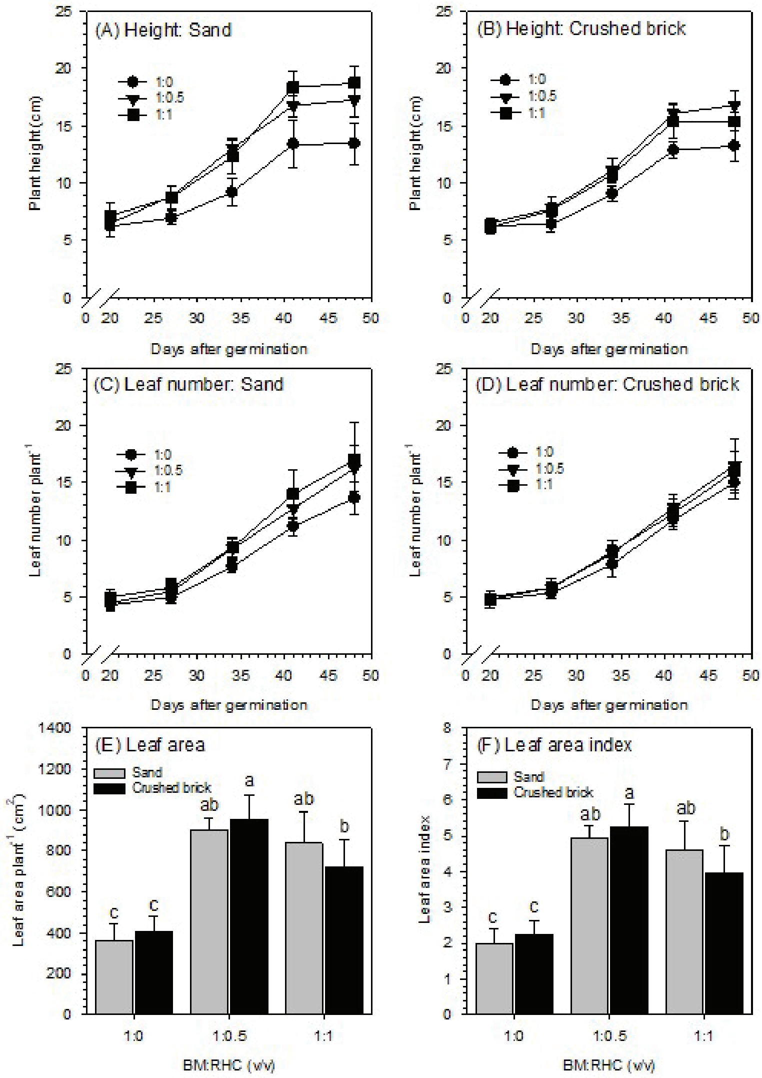

Figure 1 Height (A and B), leaf number (C and D), leaf area (E) and leaf area index (F) of pak choi as responded to basal materials (BM) of the potting mixes including sand and crushed brick supplemented with rice husk charcoal (RHC) of different ratios (BM:RHC, 1:0, 1:0.5, and 1:1 v/v). Bars with the same letters of either sub-figure (E) and (F) are not significantly different ($p \leq 0.05$; Tukey's HSD test). Error bars of sub-figure (E) and (D) represent standard deviation.

The 1:0.5 and 1:1 v/v of crushed brick treatments produced lower fresh shoot biomass than the sand treatments of respective RHC proportions (Figure 2A). Dry shoot biomass tended to decrease in crushed brick supplemented with RHC at a ratio of 1:0 and 1:1 v/v compared to sand supplemented with the respective RHC proportions (Figure 2B). Fresh- (Figure 2A) and dry shoot biomass (Figure 2B) increased in the 1:0.5 v/v in comparison to 1:0 v/v. On the contrary, the biomass tended to decrease in the 1:1 v/v compared to its lower RHC proportion (1:0.5 v/v) in crushed brick treatment.

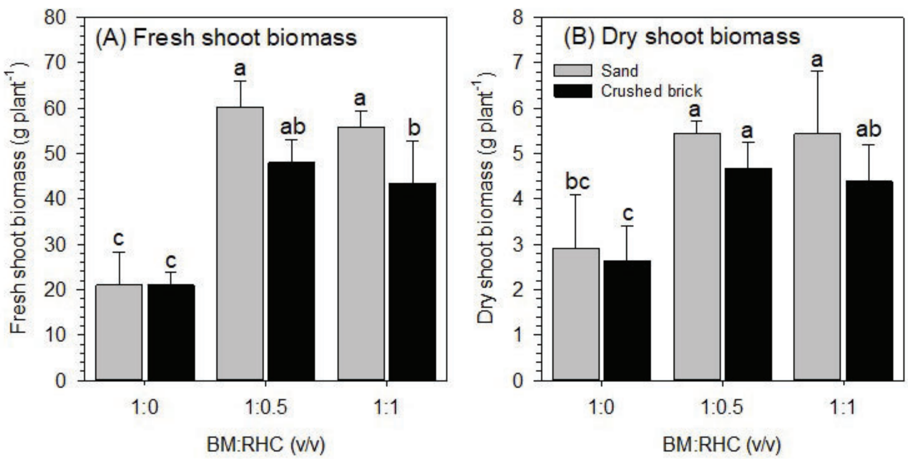

Figure 2 Fresh- (A) and dry shoot biomass (B) of pak choi as affected by basal materials (BM) of the potting mixes including sand and crushed brick supplemented with rice husk charcoal (RHC) of different ratios (BM:RHC, 1:0, 1:0.5 and 1:1 v/v). Bars with the same letters of either sub-figure (A) and (B) are not significantly different ($p \leq 0.05$; Tukey's HSD). Error bars represent standard deviation.

Discussion

The deleterious effect of crushed brick used as a basal material of the potting mix may primarily result from excessive Si supply. Butnan (2015) demonstrated that high Si content in growing media due to overdose application of eucalyptus charcoal led to the antagonistic effect of Si to Fe and Mn. Based on shoot Si content, plants have been classified as high-, intermediate-, and non-Si accumulators (Tubana *et al*., 2016; Li and Delvaux, 2019). Plants contained 1-10% Si (in dry weight) ranked as high Si accumulator, and 0.5-1% Si was intermediate, while less than 0.5% Si was non-Si accumulator (Ma *et al*., 2001). Brassica sp. was counted as a non-Si accumulator because its shoot Si concentration was less than 0.1% (Guntzer *et al*., 2012). However, it has been claimed that Brassica sp. could uptake and store high Si content in roots via an active transport process (Tubana *et al*., 2016; Haddad *et al*., 2018). High Si supply in growing media therefore rendered Si antagonistic to other cations, in particular Fe and Mn. The following are the mechanisms of the antagonistic effect of Si on other cations including Fe and Mn proposed by Liang *et al*. (2007): (i) increase in ionic strength, (ii) stimulation of unavailability of other cations via metal–phenolic complex through induction of phenolic compound releases and (iii) co-precipitation of Si with metals in growing media.

Silicon in crushed brick was achieved from the thermal transformation of soil minerals, i.e., kaolinite and quartz, as well as rice husk ash employed as raw materials in the brick production (Chuchaisong and Wongthong, 2009; Trakoolngam *et al.*, 2019). In addition, the low specific surface area and low negative surface charge causing the low cation holding capacity of crushed brick were possibly an additive effect of Si oversupply.

Raw materials of the fired clay brick in Northeast Thailand are commonly comprised of clayey soil, sand, and rice husk ash (Chuchaisong and Wongthong, 2009; Trakoolngam *et al.*, 2019). Kaolinite was a principal mineral constituted in clayey soils employed in the manufacturing brick process (Promkotra, 2013). After the moulding step, the fresh brick was heated under a peak temperature of approximately 1,200°C (Chuchaisong and Wongthong, 2009). Under the heating process, kaolinite was transformed to metakaolinite, and finally mullite and cristobalite, respectively (Lee *et al.*, 1999). Kaolinite structure was delaminated, dehydroxylated, and re-crystallized to produce not only high content of plant-available Si (Daou *et al.*, 2020) but also other new mineral products, e.g., metakaolinte, γ-alumina, Al-Si spinel, Al-rich mullite, cristobalite, and amorphous SiO_2 (Lee et al., 1999). These minerals possessed the low specific surface areas and low negative surface charges (Torres Sánchez and Tavani, 1994). Torres Sánchez and Tavani (1994) reported that the major minerals in the kaolinite heating process included 41.2%SiO_2, 22.5%Al_2O_3, and 19.2%Fe_2O_3 w/w. They also found abrupt decreases in specific surface areas of the whole sample of these minerals, i.e., 55, 46, and 2 m^2 g^{-1} with increasing heating temperatures of 100, 500, and 1,100°C, respectively. Meanwhile, the low surface charge of heated kaolinite-derived minerals was a consequence of the removal of the -OH group in the dehydroxylation reaction (Chakraborty, 2014)

At around 1,000 – 2,000°C, α-quartz (common quartz) was thermally transformed to β-quartz, high-temperature hexagonal tridymite, β-cristobalite, coesite, stishovite, and ready plant-available Si (Ringdalen, 2015). An additional Si was gained from rice husk ash– a brick raw material, which ranged 40.2 – 43.5% Si w/w (Hossain *et al.*, 2018).

The adverse effect of high RHC proportion (1:1 v/v) on fresh- and dry shoot biomass may also be attributed to the oversupply of Si. Rice husk charcoal has been chosen as an alternative Si source because it is reputed as high content of plant-available Si (Wang *et al.*, 2019) as can be demonstrated in Costa *et al.* (2003), who found 32%Si w/w constituted in RHC. It has been reported that Si-instituted minerals in RHC were phytolith [$SiO_{n/2}(OH)_{4-n}$]m, hydrated amorphous Si ($SiO_2 \cdot nH_2O$), and crystalline Si such as gonnardite ($Na_2CaAl_4Si_6O_{20} \cdot 7(H_2O)$), cristobalite [($SiO_2$)n], tridymite [($SiO_2$)n], diopside ($MgCaSi_2O_6$), kalsilite (KAlSiO4), albite [Na($AlSi_3O_8$)], and quartz [(SiO_2)n] (Xiao et al., 2014; Qian *et al.*, 2016; Li and Delvaux, 2019). As such, phytolith and amorphous Si were pointed out as the primary Si minerals in rice residue-derived charcoal produced at about 500°C which was a similar level of heating temperature for charcoal production in the current work (Li and Delvaux, 2019). Phytolith and amorphous Si in RHC were soluble and easily uptaken by plant (Li *et al.*, 2019). Overdose application of RHC therefore brought about an additive effect on Si antagonism.

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Conclusions

The results of this study were constructively demonstrated that recycling waste brick as a basal material of potting mix for pak choi production brought about the deleterious effect on pak choi's growth and yield. Supplementation of potting media with rice husk charcoal at the proportion between the basal and supplement materials to 1:0.5 could improve growth and yield of pak choi and *vice versa* for 1:1 v/v. Instead of re-utilization of waste brick as a basal material of the potting mix in crop production, its fabrication to pellets, granules, or ball material as a soil conditioner should be taken into account.

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