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Agronomic, Yielding, and Pyruvate Content of Samosir Local Shallot Due to *Trichoderma* spp.

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THE USE of *Trichoderma* spp. as a substitute has the potential to reduce the reliance on synthetic fertilizers and increase plant yield. Therefore, this study aimed to obtain (1) the types of *Trichoderma* spp., dosage, and their interactions that can improve agronomic, yielding, and pyruvate content, as well as (2) the relationship between these characteristics and yield ha^{-1} of Samosir shallot. It was conducted in Dolok Martumbur Village, Muara Subdistrict, North Tapanuli District, North Sumatra Province, Indonesia, from June to December 2021. The Factorial Randomized Block Design was selected within three replicates in this study. The types of *Trichoderma* spp. such as *T. harzianum, T. virens, T. viridee,* and *T. asperellum* were used as the first factor and the second was dosages of 0, 20, 40, and 60g $polybag^{-1}$. The data were processed with ANOVA, followed by DMRT at $P< 0.05$, and correlated with Pearson using IBM SPSS. Based on the results, the highest increase in agronomic, yielding, and total pyruvate was found in *T. asperellum* isolates. There were increased roots fresh weight, number of bulbs, bulbs diameter, and total pyruvate by 40.23; 15.71; 15.49; and 23.34% along with increasing the isolate dosage up to 60 g $polybag^{-1}$. Likewise, their interactions of *T. asperellum* isolates at a dosage of 20 to 40g $polybag^{-1}$ could be increased the highest bulbs weight, yield ha^{-1}, and total pyruvate. Furthermore, root fresh weight, the number of bulbs, bulbs weight, and total pyruvate positively and significantly correlated with increasing yield ha^{-1}.

Keywords: Characteristics, Correlation, Dosage, Fungal isolates.

Introduction

Trichoderma is a genus of fungi that belongs to the family Hypocreaceae and consists of more than 100 species (Druzhinina et al., 2006). Several *Trichoderma* spp. such as *T. harzianum, T. viride, T. reesi, T. polysporum, T. koningii*, and others have been reported as biofertilizers. Among Trichoderma species, *T. harzianum* and *T. viride* are mostly used (Gupta et al., 2014). These species are also reported as plant growth promoters that are morphologically characterized by increased root and shoot biomass (Stewart & Hill, 2014). Furthermore, they can also increase shallot (*Allium cepa* L.) yield by 7.99% due to *T. harzianum* dose of 5g m^{-2} (Altintas & Bal, 2008), 76.47% with *T. viride* dose of 10g kg^{-1} soil (Rajeswari et al., 2019), and around of 34.4; 28.1; and 68.8% due to *T. virens*, *T. album*, and *T. koningii*, respectively (Elshahawy et al., 2017), as well as 11.98 and 13.37% due to *T. harzianum* and *T. viride* (Bayoumi et al., 2019).

Stewart & Hill (2014) reported several mechanisms of *Trichoderma* spp. in stimulating plant growth through increased nutrient uptake, carbohydrate metabolism and photosynthesis, synthesis of phytohormones, and influencing hormones such as indole acetic acid (IAA), gibberellic acid, and ethylene. It was discovered that several plant hormones from the application of *Trichoderma* spp. could be affected by root development, such as *T. harzianum* producing harzionalide and harzianic acid (Cai et al., 2013; Vinale et al., 2013), *T. asperellum* produced IAA

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(Ortega-García et al., 2015), and *T. virens* produced auxin (Contreras-Cornejo et al., 2009). Furthermore, *T. virens* and *T. atroviride* significantly increased the number and density of lateral roots, root hair length, and produced abscisic acid and L-proline (Contreras-Cornejo et al., 2014).

These results showed that the use of certain *Trichoderma* spp. is beneficial as it can increase the yield of shallot plants and reduce the application of synthetic fertilizers. This is specifically for the ten provinces in Indonesia with the highest shallot yield centers, namely Central Java, East Java, West Nusa Tenggara, West Sumatra, South Sulawesi, West Java, North Sumatra, Yogyakarta, Bali, and Jambi. These provinces contributed 97.89% of the total shallot yield with a value of 2,004,590 tons in 2021 (Statistics Indonesia, 2022). However, farmers in North Tapanuli, North Sumatra Province, Indonesia, still rely on chemical fertilizers to increase the yield of the local variety in Samosir shallot. When this agronomic technique is consistently used, it will decrease shallot yield due to low soil fertility.

Alternative methods for reducing excessive chemical fertilization are needed through *Trichoderma*-based biofertilizers. Therefore, this study aimed to (1) obtain *Trichoderma* spp., applicable rates, and their interactions to the improvement of agronomic yield and pyruvate content, as well as (2) determine the relationship between these characteristics and the yield ha^{-1} of local variety in Samosir shallot.

Materials and Methods

Location study and propagation of Trichoderma spp. isolates

Samosir shallot was planted in Dolok Martumbur Village (98.95215°E; 2.3242°N), Muara Subdistrict, North Tapanuli District, North Sumatra, Indonesia, from June to December 2021. The planting area conditions were an altitude, temperature, humidity, and air pressure at 1,000 m above sea level, 22.8°C, 67%, and 1013 hPa, respectively. Type-confirmed *Trichoderma* spp isolates from the collection of Pests and Diseases Laboratory, Faculty of Agriculture, Universitas Sumatera Utara, Indonesia. The isolates were cultured on solid maize media that had been boiled (Novianti, 2018) in the Laboratory of North Tapanuli Agriculture Department. Selection of maize media is due to the growth of *Trichoderma* colony diameter was not significantly different from PDA (Potato Dextrose Agar) media based on Noviyanti (2018). Maize ground to a small size of 20 g and boiled for 10min, then put into transparent vapor-proof plastic and wrapped. The media was put into an autoclave for 60 min and refrigerated for 12h, then the *Trichoderma* isolates were inserted and stored for 4 d until they were fully developed. The successfully cultured isolate was characterized by its green color and fragrant aroma.

Sources and criteria for seedlings of shallot bulbs

Samosir shallot bulb was obtained from Bakkara Village (98°50’45” E; 2°19’26” N), Bakti Raja Subdistrict, Humbang Hasundutan District, Indonesia, with a homogenous size bulbs diameter of 1.5cm. The criteria for the bulb used as seedlings were healthy, firm, glossy outer skin, and the bulb skin was not peeled off.

Growing media and planting shallot bulbs

The planting media used was a mixture of topsoil with a depth of 0-20cm, dolomite, and chicken manure at a dose of 10 tons ha^{-1} or equivalent to 25g/polybag. The media mixture was homogenized and placed in 5kg polybags with a 40cm diameter and 25cm height. The planting media was fertilized with SP-36 at a rate of 5g polybag^{-1} at three days before planting. The bulb was planted in polybags with two bulbs per polybag and watered. Subsequently, the polybags were spaced at a distance of 30cm × 40cm for shallot planting. Nitrogen-Phosphorus-Potassium (NPK) is a common fertilizer in a 15-15-15 ratio was carried out at planting, at an interval of two to four weeks after planting with a dose of 1 ton ha^{-1} using a furrow system. The irrigation was performed daily based on field conditions and weeds were controlled manually.

Study design, parameters, and data analysis

This study used a randomized block design with three replicates. The potentiality of each *Trichoderma* isolates were the first determinate parameter, namely *Trichoderma harzianum* (Thm), *Trichoderma virens* (Tvs), *Trichoderma viride* (Tve), and *Trichoderma asperellum* (Tam). While the applicable rate of the four tested *Trichoderma* isolates was the second parameter that varied from 0, 20, 40, to 60g polybag^{-1}. The dose determination of *Trichoderma* spp. at 20g refers to Yusrinawati et al. (2017). The parameters measured were agronomic characteristics, namely root volume, root fresh weight, and dry stover weight. The yielding characteristics included bulb number and diameter, bulb weight, and yield ha^{-1}. Likewise, pyruvate

characteristics such as levels of pyruvic acid and total pyruvate plant^{-1}. Agronomic characteristics were measured 76 days after planting, and yielding characteristics were measured after full maturation of the tested plant during harvesting time, which was 83 days after planting.

The measurement of pyruvic acid was carried out using the Schwimmer & Weston (1961) method. The 10 g of the bulbs was weighed and 10 mL of distilled water was added and homogenized for 3 min. The extracted sample was centrifuged for 10min at 20,000rpm and 1.5mL of the supernatant was taken and diluted with distilled water up to 10 times. Subsequently, 0.5mL of the aliquot was added to 1mL of 2,4-dinitrophenylhydrazine (DNPH), and 1.5mL of distilled water to the reaction tube. The reaction mixture was vortexed at 37°C for 10min and cooled. Moreover, 5mL of 0.6mol L^{-1} NaOH was added, and the absorbance was measured using a UV-spectrophotometer at 420nm. A standard solution of pyruvic acid was prepared at concentrations of 0.04-0.4mmol L^{-1} in distilled water. The concentration of pyruvic acid was expressed in µmol/100 g. The total pyruvate was calculated using the formula Anthon & Barrett (2003), while yield ha^{-1} using the formula Novita et al. (2022). Total pyruvate was calculated using the Anthon & Barrett (2003) formula, while yield ha^{-1} was adopted by Peace Corps (1980) and shown in Equations 1, 2.

$$\text{Total pyruvate} = \text{Pyruvic acid content per plant} \times \text{bulbs weight} \quad (1)$$

$$\text{Yield ha}^{-1} = \frac{\text{Land area/ha}}{\text{Plant spacing}} \times \text{bulbs weight per plant} \quad (2)$$

Agronomic yield and pyruvate levels were processed using ANOVA, followed by DMRT at $P< 0.05$, and analyzed for Pearson correlation between parameters using IBM SPSS Statistics.

Results and Discussion

Agronomic characters

The type of *Trichoderma* spp. isolates significantly increased the roots volume, roots fresh weight, and dry stover weight of Samosir shallot plants as presented in Table 1. The applicable rates of *Trichoderma* spp. isolates only significantly increases the roots fresh weight of Samosir shallot but had an insignificantly affected on the roots volume and dry stover weight. Meanwhile, their interactions were insignificantly affected by the roots volume, roots fresh weight, and dry stover weight of Samosir shallot.

The results showed that *T. asperellum* isolate had a higher ability to increase the roots volume, roots fresh weight, and dry stover weight by 6.58 cc; 11.82g; and 181.60g, respectively compared to other isolates. It was also discovered that the higher the isolate applicable rates up to 60g polybag^{-1}, the greater the increase in the roots fresh weight by 40.23% compared to the control. The relationship between the applicable rates of *Trichoderma* spp. isolates with the roots fresh weight of Samosir shallot plant could be seen in Fig. 1A. The applicable rates of *Trichoderma* spp. isolates had a linear relationship pattern to roots fresh weight ($\hat{y}$= 1.0687x+7.1566) of Samosir shallot.

Yielding characters

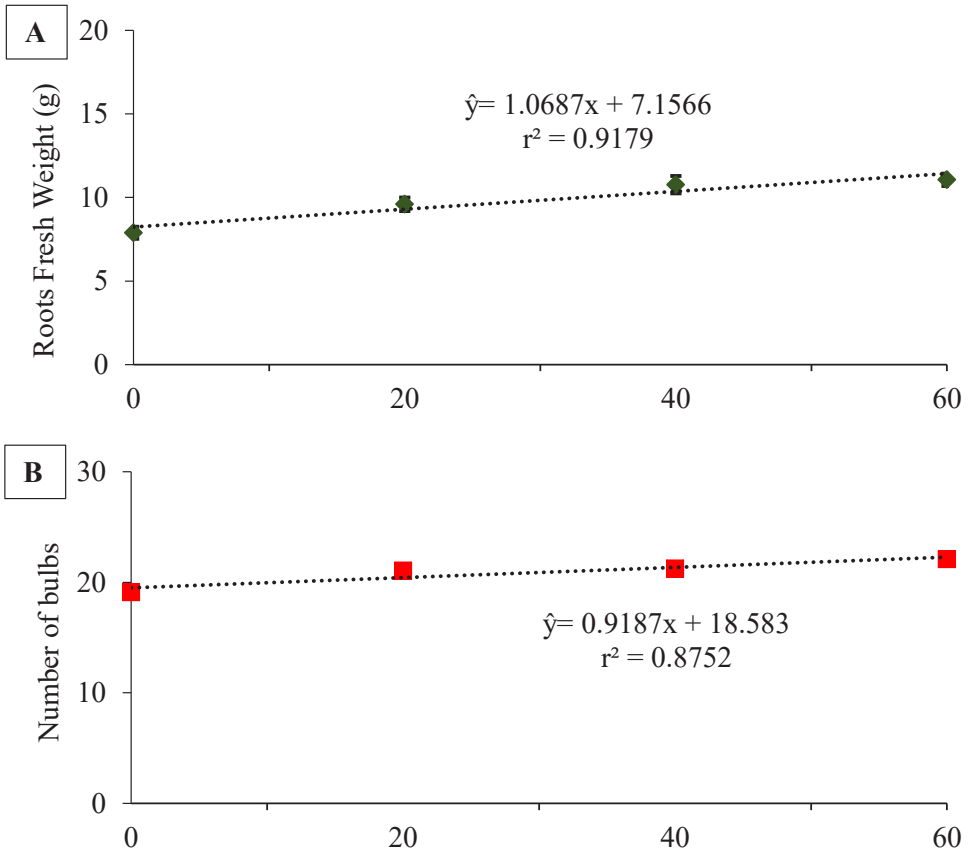
The *Trichoderma* spp. isolates significantly increased the weight of the bulbs and yield ha^{-1} of Samosir shallot, but it had an insignificantly affected on the number and diameter of the bulbs (Table 2). The applicable rates of *Trichoderma* spp. isolates significantly increased the number and diameter of shallot bulbs, but it were insignificantly affected the bulbs weight and yield ha^{-1}. Likewise, their interactions also significantly increased the bulbs weight and yield ha^{-1} of the Samosir shallot, but it did not significantly affect the number and diameter of the bulbs.

The results showed that *T. asperellum* isolate had a higher ability to increase the weight and yield of the bulbs were 186.02g and 7.75 tons ha^{-1} of Samosir shallot compared to other isolates. The higher the isolate applicable rates up to 60g polybag^{-1}, the greater the number and diameter of the bulb by 15.71% and 15.49% compared to the control. Similarly, the interactions of *T. asperellum* with 20g polybag^{-1} (Tam-20) showed the highest bulbs weight and yield by 207.18g and 8.63 tons ha^{-1}, respectively compared to other interactions. The relationship between the applicable rates of *Trichoderma* spp. isolates with the bulbs number and diameter of Samosir shallot plant could be seen in Figs. 1B and 1C. The applicable rates of *Trichoderma* spp. isolates had a linear relationship pattern to the bulbs number and diameter ($\hat{y}$= 0.9187x+18.583 and $\hat{y}$= 0.5138x+10.305) of Samosir shallot.

TABLE 1. The effect of Trichoderma spp. isolates, dosage, and their interactions on the agronomic characters in Samosir shallot

Isolate types	Dosage (g polybag^{-1})				Average
	0	20	40	60	
Roots volume (cc)					
T. harzianum (Thm)	4.50 ± 0.33 ns	6.46 ± 0.47 ns	6.67 ± 0.29 ns	4.42 ± 0.35 ns	5.51 ± 0.30 b
T. virens (Tvs)	4.29 ± 0.28 ns	4.92 ± 0.39 ns	4.92 ± 0.31 ns	5.04 ± 0.31 ns	4.79 ± 0.08 b
T. viridee (Tve)	5.79 ± 0.31 ns	4.75 ± 0.34 ns	4.67 ± 0.15 ns	4.75 ± 0.44 ns	4.99 ± 0.13 b
T. asperellum (Tam)	6.75 ± 0.31 ns	6.83 ± 0.21 ns	5.58 ± 0.31 ns	7.17 ± 0.29 ns	6.58 ± 0.17 a
Average	5.33 ± 0.29 ns	5.74 ± 0.26 ns	5.46 ± 0.22 ns	5.34 ± 0.31 ns	CV= 22.65%
Roots fresh weight (g)					
T. harzianum (Thm)	8.01 ± 0.41 ns	9.85 ± 0.53 ns	12.15 ± 0.21 ns	10.32 ± 0.43 ns	10.08 ± 0.43 b
T. virens (Tvs)	6.17 ± 0.15 ns	8.47 ± 0.63 ns	10.19 ± 0.68 ns	11.16 ± 0.73 ns	9.00 ± 0.55 bc
T. viridee (Tve)	7.68 ± 0.12 ns	8.28 ± 0.74 ns	8.04 ± 0.44 ns	9.66 ± 0.41 ns	8.41 ± 0.22 c
T. asperellum (Tam)	9.69 ± 0.65 ns	11.80 ± 0.36 ns	12.69 ± 0.51 ns	13.11 ± 0.55 ns	11.82 ± 0.38 a
Average	7.89 ± 0.36 b	9.60 ± 0.41 a	10.77 ± 0.53 a	11.06 ± 0.37 a	CV= 18.66%
Dry stover weight (g)					
T. harzianum (Thm)	153.40 ± 3.89 ns	162.92 ± 6.65 ns	170.43 ± 8.44 ns	159.52 ± 4.07 ns	161.57 ± 1.78 b
T. virens (Tvs)	165.12 ± 4.10 ns	151.38 ± 5.24 ns	158.08 ± 2.58 ns	143.14 ± 6.82 ns	154.43 ± 2.35 b
T. viridee (Tve)	150.52 ± 2.59 ns	148.81 ± 1.26 ns	141.83 ± 2.42 ns	190.02 ± 2.05 ns	157.79 ± 5.45 b
T. asperellum (Tam)	160.30 ± 6.90 ns	184.97 ± 6.21 ns	185.52 ± 2.70 ns	195.60 ± 0.90 ns	181.60 ± 3.75 a
Average	157.33 ± 1.65 ns	162.02 ± 4.12 ns	163.97 ± 4.64 ns	172.07 ± 6.24 ns	CV= 14.46%

Note: the average followed by a different letter in the same column showed a significantly affected on the DMRT at P< 0.05 ± standard error. ns= not significant. CV= coefficient of variation.



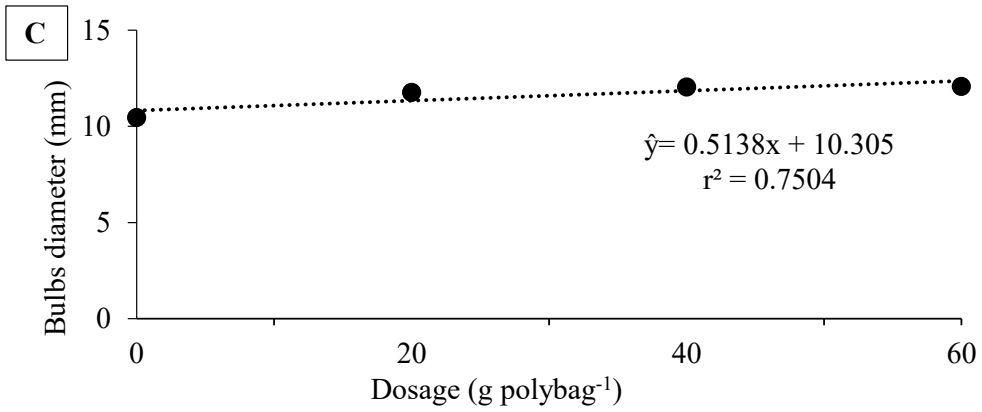


Fig. 1. The relationship between the dosage of *Trichoderma* spp. isolate with the roots fresh weight (A), the number of bulbs (B), and bulbs diameter (C) of Samosir shallot

TABLE 2. The effect of *Trichoderma* spp. isolates, dosage, and their interactions on the yielding characters in Samosir shallot

Isolate types	Dosage (g polybag^{-1})				Average
	0	20	40	60	
Number of bulbs					
T. harzianum (Thm)	18.92 ± 0.38 ns	21.17 ± 0.06 ns	22.08 ± 0.14 ns	21.92 ± 0.26 ns	21.92 ± 0.36 ns
T. virens (Tvs)	19.08 ± 0.10 ns	20.83 ± 0.08 ns	21.17 ± 0.08 ns	22.42 ± 0.21 ns	20.88 ± 0.34 ns
T. viridee (Tve)	19.25 ± 0.27 ns	19.83 ± 0.11 ns	20.25 ± 0.22 ns	22.17 ± 0.27 ns	20.38 ± 0.32 ns
T. asperellum (Tam)	19.17 ± 0.19 ns	22.42 ± 0.20 ns	21.50 ± 0.07 ns	21.92 ± 0.24 ns	21.25 ± 0.36 ns
Average	19.10 ± 0.04 b	21.06 ± 0.27 a	21.25 ± 0.19 a	22.10 ± 0.06 a	CV= 6.85%
Bulbs weight (g)					
T. harzianum (Thm)	65.16 ± 3.53 de	72.66 ± 3.33 b-e	80.39 ± 2.54 a-e	52.72 ± 2.19 e	67.73 ± 2.95 b
T. virens (Tvs)	88.74 ± 3.32 a-d	52.51 ± 2.02 e	71.94 ± 2.16 b-e	89.49 ± 1.90 a-d	75.67 ± 4.36 b
T. viridee (Tve)	77.10 ± 1.77 a-e	72.34 ± 1.28 b-e	70.15 ± 2.59 cde	92.85 ± 0.76 a-d	78.11 ± 2.56 b
T. asperellum (Tam)	68.82 ± 4.27 cde	103.59 ± 2.59 a	101.49 ± 0.79 ab	98.13 ± 2.09 abc	93.01 ± 4.07 a
Average	74.95 ± 2.61 ns	75.28 ± 5.27 ns	80.99 ± 3.59 ns	83.30 ± 5.17 ns	CV= 20.18%
Bulbs diameter (mm)					
T. harzianum (Thm)	10.30 ± 0.10 ns	11.58 ± 0.21 ns	11.54 ± 0.17 ns	11.64 ± 0.20 ns	11.27 ± 0.16 ns
T. virens (Tvs)	10.68 ± 0.16 ns	11.34 ± 0.07 ns	11.67 ± 0.04 ns	11.59 ± 0.06 ns	11.32 ± 0.11 ns
T. viridee (Tve)	10.35 ± 0.07 ns	11.93 ± 0.04 ns	12.54 ± 0.29 ns	12.44 ± 0.17 ns	11.81 ± 0.25 ns
T. asperellum (Tam)	10.50 ± 0.14 ns	12.24 ± 0.06 ns	12.43 ± 0.09 ns	12.66 ± 0.02 ns	11.96 ± 0.25 ns
Average	10.46 ± 0.04 b	11.77 ± 0.10 a	12.04 ± 0.13 a	12.08 ± 0.14 a	CV= 7.13%
Yield (ton ha^{-1})					
T. harzianum (Thm)	5.43 ± 0.29 de	6.06 ± 0.28 b-e	6.70 ± 0.21 a-e	4.39 ± 0.18 e	5.64 ± 0.25 b
T. virens (Tvs)	7.39 ± 0.28 a-d	4.38 ± 0.17 e	5.99 ± 0.18 b-e	7.46 ± 0.16 a-d	6.31 ± 0.36 b
T. viridee (Tve)	6.42 ± 0.15 a-e	6.03 ± 0.11 b-e	5.85 ± 0.22 cde	7.74 ± 0.06 a-d	6.51 ± 0.21 b
T. asperellum (Tam)	5.73 ± 0.36 cde	8.63 ± 0.22 a	8.46 ± 0.07 ab	8.18 ± 0.17 abc	7.75 ± 0.34 a
Average	6.25 ± 0.22 ns	6.27 ± 0.44 ns	6.75 ± 0.30 ns	6.94 ± 0.43 ns	CV= 20.17%

Note: the average followed by a different letter in the same column showed a significantly affected on the DMRT at P< 0.05 ± standard error. ns= not significant. CV= coefficient of variation.

Pyruvate level

The results showed that the types of *Trichoderma* spp. isolates, applicable rates, and their interaction significantly increased the total pyruvate per plant of Samosir shallot, but it had an insignificant effect on the pyruvate acid content (Fig.2 and Table 3). *T. asperellum* isolate had a higher ability to increase the total pyruvate per plant by 364.35µmol than other isolates (Fig. 2C). The total pyruvate per plant also increased with a higher isolate applicable rates of up to 60g polybag^{-1} by 23.34% compared to the control (Fig. 2D). There was a linear pattern between isolate applicable rates and total pyruvate per plant (ŷ= 24.234x+265.02). Similarly, the interactions of *T. asperellum* isolate with 40g polybag^{-1} (Tam-40) showed the highest total pyruvate of 439.34µmol compared to other interactions.

Correlation value between characteristics

The correlation between shallot plant parameters due to the types of *Trichoderma* spp. isolates, applicable rates, and their interaction as shown in Table 4. It was discovered that the characters of roots fresh weight and the number of bulbs have a positive and significantly correlated were 0.469** and 0.313* in increasing bulbs weight. The other results also showed that the total pyruvate per plant had a positive and significantly affected by roots fresh weight, number of bulbs, bulbs diameter, and bulbs weight of Samosir shallot with values of 0.434**; 0.314*; 0.370**; and 0.859**, respectively. Similarly, the yield ha^{-1} of Samosir shallot had a positive and significantly affected by roots fresh weight, number of bulbs, bulbs weight, and total pyruvate per plant with values of 0.469**; 0.313*; 1.000**; and 0.859**, respectively.

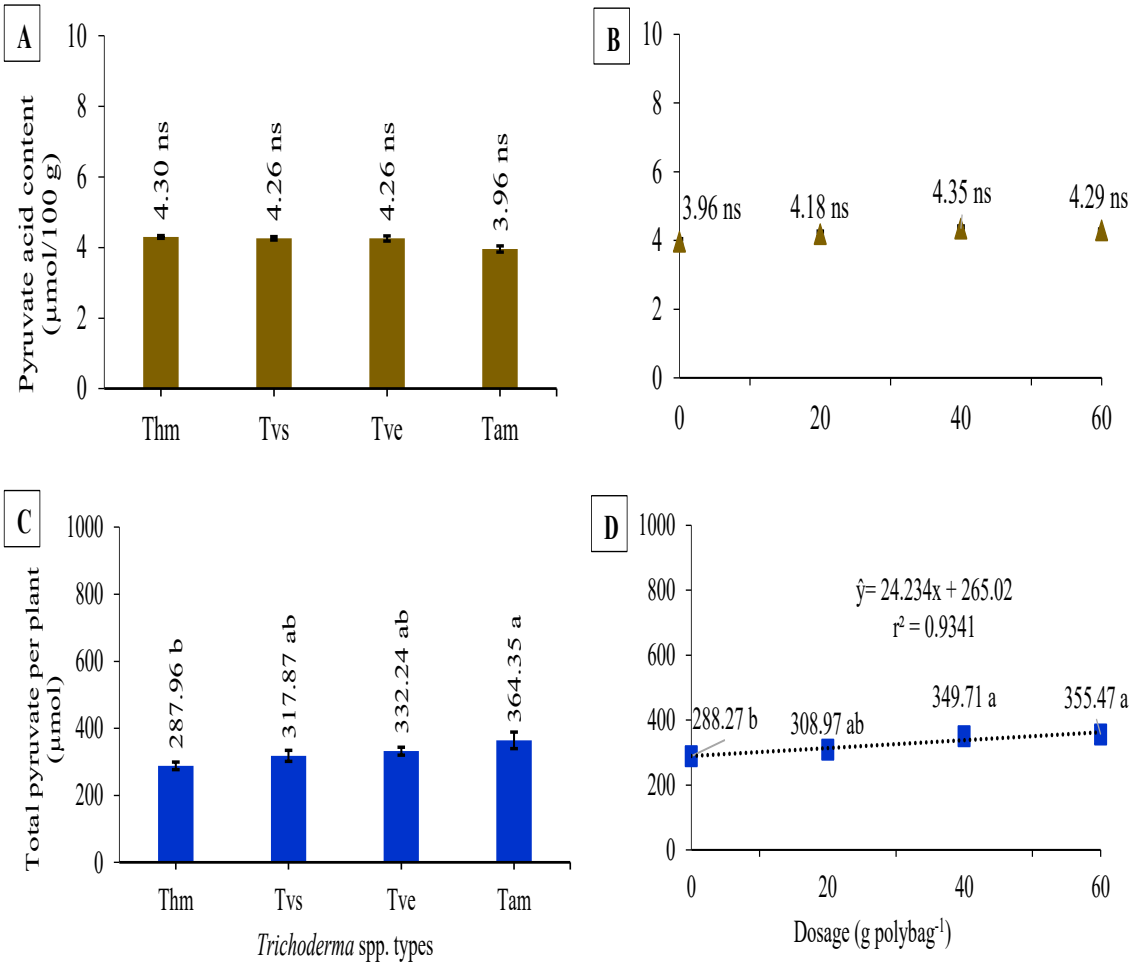


Fig. 2. The pyruvate acid content and total pyruvate per plant of Samosir shallot due to the isolate types (A, C) and dosage (B, D) [Thm= *Trichoderma harzianum*, Tvs= *Trichoderma virens,* Tve= *Trichoderma viridee,* Tam= *Trichoderma asperellum).* The vertical lines indicated the standard error]

TABLE 3. Interaction effect of isolate types and dosage on the pyruvate acid content and total pyruvate per plant of Samosir shallot

Isolate types	Isolate dosage	Pyruvate acid (µmol/100 g)	Total pyruvate per plant (µmol)
Thm	0	4.28 ± 0.06 ns	273.50 ± 12.04 cd
	20	4.41 ± 0.04 ns	318.67 ± 13.38 bcd
	40	4.10 ± 0.03 ns	327.28 ± 8.53 a-d
	60	4.41 ± 0.00 ns	232.37 ± 9.60 d
Tvs	0	4.01 ± 0.08 ns	351.29 ± 11.72 abc
	20	4.47 ± 0.06 ns	232.74 ± 7.91 d
	40	4.30 ± 0.07 ns	304.60 ± 3.62 bcd
	60	4.27 ± 0.05 ns	382.85 ± 10.41 abc
Tve	0	4.04 ± 0.03 ns	309.48 ± 4.63 bcd
	20	4.04 ± 0.03 ns	292.08 ± 5.78 bcd
	40	4.65 ± 0.03 ns	327.62 ± 13.52 a-d
	60	4.30 ± 0.02 ns	399.78 ± 5.26 ab
Tam	0	3.51 ± 0.17 ns	218.78 ± 6.56 d
	20	3.81 ± 0.16 ns	392.39 ± 18.37 ab
	40	4.33 ± 0.02 ns	439.34 ± 1.70 a
	60	4.18 ± 0.05 ns	406.87 ± 4.62 ab
CV (%)		12.13	18.73

Note: the average followed by a different letter in the same column showed a significantly affected on the DMRT at $P<0.05$ ± standard error. ns= not significant. CV= coefficient of variation.

Effect of Trichoderma spp. isolates

The characteristics of root volume and fresh weight, dry stover and bulb weight, yield ha^{-1}, and total pyruvate of Samosir shallot plants were significantly affected by the type of *Trichoderma* spp. isolates and the highest value was found in *the T. asperellum* (Tam) isolate. The increase in agronomic characters, yield, and total pyruvate of the shallot plant was caused by *T. asperellum* isolate, which affected root development, including the length, density, and hairs. Moreover, root development can be caused by the IAA auxin activity produced by *T. asperellum* isolate and impacts increased nutrient uptake, dry stover production, and bulbs weight. It was caused by the root volume that highly correlated with the dry stover weight of 0.650**. The root fresh weight also had a highly correlated with the bulbs weight and total pyruvate of Samosir shallot by 0.469** and 0.434**, respectively (Table 4). These findings were supported by Li et al. (2018) that *Trichoderma* spp. had a growth-promoting effect by secreting indole acetic acid (IAA) and increasing nutrient uptake. Zhao & Zhang (2015) reported that *T. asperellum* Q1 significantly produced IAA hormone and increased root length compared to the control. Furthermore, Cai et al. (2013); Vinale et al. (2013); and Contreras-Cornejo et al. (2009) added that the production of plant hormones such as auxin, harzianic acid, and harzionalide by *Trichoderma* spp. played a role in improving the root development of the plant. Singh et al. (2018) also found that *Trichoderma asperellum* T42 can increase root hairs, lateral roots, and root biomass. Rivera-Méndez et al. (2021) discovered that *T. asperellum* significantly increased the fresh and dry weight of shallot bulbs which were higher than *T. harzianum*, *T. virens*, and the control.

In another response, *Trichoderma* spp. isolates can increase the activity of the enzyme pyruvate decarboxylase and result in an increase in sugar metabolism (Ismond et al., 2003). The visible response to this metabolic enhancement was an increase in plant biomass (Elkelish et al., 2020). In the present study, it was seen that an increase in bulb weight was positively and significantly correlated to the total pyruvate. It indicated that total pyruvate increased along with the increase in bulb weight of shallot plants.

TABLE 4. Correlation matrix between the parameters of the Samosir shallot plant due to the types of *Trichoderma* spp., dosage, and their interactions

Characters	RV	RFW	DSW	NB	BD	BW	PAC	TPP	Y
RV	1	-0.001	0.650**	0.097	0.345*	0.032	0.016	0.052	0.032
RFW		1	0.093	0.306*	0.249	0.469**	-0.101	0.434**	0.469**
DSW			1	0.146	0.565**	0.251	-0.120	0.200	0.251
NB				1	0.399**	0.313*	-0.037	0.314*	0.313*
BD					1	0.251	0.190	0.370**	0.251
BW						1	-0.415**	0.859**	1.000**
PAC								0.486	0.003
TPP								1	0.859**
Y									1

Note: ** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed). n= 48 samples. RV= roots volume; RFW= roots fresh weight; DSW= dry stover weight; NB= number of bulbs; BD= bulbs diameter; BW= bulbs weight; PAC= pyruvate acid content; TPP= total pyruvate per plant; Y= yield.

Applicable rates effect

The roots fresh weight, bulbs number and diameter, and the total pyruvate of Samosir shallot were significantly affected by the isolate applicable rates. These characteristics increased with a high isolate applicable rates up to 60g polybag^{-1} were 40.23; 15.71; 15.49; and 23.34%, respectively compared to the control. It was caused by a higher applicable rate provided a larger population of *T. harzianum, T. virens, T. viride,* and *T. asperellum* in this study, as well as the ability to produce plant growth hormones that increase nutrient uptake. The production of these hormones will affect the characteristics of the root in absorbing nutrients. It was seen that the roots fresh weight had a positive and significantly correlated with an increasing number of bulbs, bulbs weight, and the total pyruvate per plant of Samosir shallot with values were 0.306*; 0.469**; and 0.434**, respectively (Table 4). This finding was supported by Azarmi et al. (2011), that the application of T. *harzianum* T447 significantly increased the levels of Ca^{2+}, Mg^{2+}, P, K^{+} in the root by 5.59; 3.68; 24.35; and 10.68 times, as well as in the shoot of 6.49; 3.14; 2.37; and 8.67 times of tomato seedlings compared to the control. Several plant hormones were reported to affect root development, such as harzionalide and harzianic acid from *T. harzianum* (Cai et al., 2013; Vinale et al., 2013), auxin from *T. virens* (Contreras-Cornejo et al., 2009), and IAA from *T. asperellum* (Ortega-García et al., 2015). Rivera-Méndez et al. (2020) discovered that the highest isolate dose of *T. asperellum* BCC1, namely 30.5 tons ha^{-1} increased the yield of shallot bulbs by 20.4%. Yusrinawati et al. (2017) also found an increase in the number of tillers and the bulbs fresh weight with increasing bio-activator doses of *Trichoderma* spp. up to 20g plant^{-1} by 13.08 and 34.43%, respectively compared to the control. Furthermore, Ortega-García et al. (2015) added that the biomass of bulbs increased with higher isolate doses of *T. asperellum* up to 100%.

Interaction effect of isolate types and applicable rates

The interaction of *T. asperellum* isolate with applicable rates of 20 and 40 g polybag^{-1} (Tam-20 and Tam-40) showed the highest bulbs weight, yield ha^{-1}, and total pyruvate with values of 103.59 g; 8.63 tons ha^{-1}, and 439.34 µmol compared to other interactions. It was due to *T. asperellum* isolate ability to stimulate the growth of shallots, as indicated by the development of

roots, such as the increasing of lateral roots and root volume. Moreover, the root volume due to *the T. asperellum* isolate significantly increased compared to other isolates. Based on Table 1, the interaction of *T. asperellum* at applicable rate of 20g polybag^{-1} (Tam-20) showed the highest root volume compared to other interactions. Similarly, the roots fresh weight also had a positive and significantly correlated with bulbs weight, total pyruvate, and yield ha^{-1} of Samosir shallot (Table 4). This finding was supported by Stewart & Hill (2014) that an increase in root and shoot biomass indicated plant growth stimulation due to the application of *Trichoderma* spp. Sudantha et al. (2020) reported an increase in the bulb's fresh weight with a high applicable rates of *Trichoderma* spp. up to 20 mL plant^{-1} of 114.29%. Ningsih et al. (2019) also added that the application of *Trichoderma* spp. up to 20 mL polybag^{-1} showed the highest bulbs fresh weight by 50.18% compared to the control.

This study provided the potentiality of *T. asperellum* isolate and their optimized minimum applicable rate of 20 g polybag^{-1} compared with the corresponding rate of other *Trichoderma* spp. These results can be recommended to farmers to increase shallots' productivity, reduce the use of chemical fertilizers, and save production costs.

Conclusions

T. asperellum isolate potentially improved the agronomic yield and total pyruvate characteristics of Samosir shallot compared to other isolates. An increase in isolate applicable rates up to 60 g polybag^{-1} also increased highest the root's fresh weight, number of bulbs, bulbs diameter, and total pyruvate were 40.23; 15.71; 15.49; and 23.34%, respectively. The interaction of *T. asperellum* isolate with a applicable rate of 20 g polybag^{-1} had a positive response to bulb weight and yield ha^{-1}, but 40 g polybag^{-1} can also be used. Moreover, yield ha^{-1} of shallot was positively and significantly affected by the root's fresh weight, number of bulbs, bulbs weight, and total pyruvate.

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