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Emergence and initial growth of tomato seedlings (*Solanum lycopersicum* L.) in different substrates

Emergencia y crecimiento inicial de plántulas de tomate (*Solanum lycopersicum* L.) en diferentes sustratos

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Abstract

Substrate is one of the fundamental factors in tomato seedling production. The emergence and initial growth of tomato seedlings (*Solanum lycopersicum* L.) in different substrates was evaluated. The research was carried out at the Maranatha Educational Unit, located in El Carmen, Manabí, Ecuador. Polystyrene culture trays with 50 cells (volume 300 cm^3) were used. The seeds used were of the Floradel variety. Three treatments (substrates) were established: agricultural soil (black soil, T1), cocoa harvest residues (cocoa soil, T2) and wood cuttings (sawdust, T3), with three replicates, each with 50 plants, in a totally randomized block treatment design, each tray corresponding to one treatment. The variables evaluated were emergence (%) and seedling height (cm), and in the last sampling, stem diameter (mm) was measured. Seedling emergence averaged 72%. T1 showed 83% emergence and seedling height of 8.13 cm and 2.45 mm stem diameter. It was concluded that the black soil generated the greatest development of the tomato seedlings, presenting the greatest height and diameter, even though they did not have the greatest emergence.

Keywords: *Solanum lycopersicum*; tomato; emergence; initial growth.

Resumen

El sustrato es uno de los factores fundamentales en la producción de almácigos de tomate. Se evaluó la emergencia y crecimiento inicial de plántulas de tomate (*Solanum lycopersicum* L.) en diferentes sustratos. La investigación se realizó en la Unidad Educativa Maranatha, ubicada en El Carmen, Manabí, Ecuador. Se utilizaron bandejas de cultivo de poliestireno con 50 alveolos (volumen 300 cm^3). Las semillas utilizadas fueron de la variedad Floradel. Se establecieron tres tratamientos (sustratos): tierra agrícola (tierra negra, T1), restos de cosecha de cacao (tierra de cacao, T2) y restos de corte de madera (aserrín, T3), con tres repeticiones, cada una con 50 plantas, en un diseño de tratamientos en bloques totalmente al azar, cada bandeja correspondió a un tratamiento. Las variables evaluadas fueron emergencia (%) y altura de las plántulas (cm), y en el último muestreo se midió el diámetro del tallo (mm). La emergencia de las plántulas alcanzó en promedio 72%. T1 presentó 83% de emergencia y altura de las plántulas de 8,13 cm y 2,45 mm de diámetro del tallo. Se concluye que la tierra negra genera el mayor desarrollo de las plántulas de tomate, al presentar mayor altura y diámetro, aun cuando no tuvieron la mayor emergencia.

Palabras clave: *Solanum lycopersicum*; tomate; emergencia; crecimiento.

Introduction

In intensive agricultural production systems, such as horticultural and ornamental production, there is a gradual replacement of traditional crop management by other farming systems (Valenzuela and Gallardo, 2002; Monge, 2007).

The cultivation of vegetables has presented changes in its entire conception; this new situation is characterized by a greater specialization of the different areas of work. As a result of this specialization, there is a gradual change in the sowing methods traditionally used, mainly due to the existence of limiting factors for the development of crops in natural soil, particularly salinization, diseases, use of substrates and depletion of agricultural soils (Pastor, 1999; Richmond, 2010).

Commercial seedling cultivation is an efficient way to obtain homogeneous and vigorous vegetable plants (Ge et al., 2012). The substrate of the seedlings plays an important role in their cultivation. High quality substrates generate healthy and potential plants to achieve high yields of vegetables. A suitable medium must provide the conditions for safe growth and development, with sufficient nutrients and water, which allow the roots to absorb oxygen and carry out gas exchange (Tam and Wang, 2015); therefore, it is necessary to use substrates and methodologies that allow a synchronous and homogeneous germination with high-quality seedlings at low cost.

During 2017, 186 million tons of tomato (*Solanum lycopersicum* L.) were produced in the world on a surface of more than 4 million hectares in about 160 different countries (General Coordination of the National Information System (CGSIN; 2018)). Total production in the world has increased by more than 35% in the last 10 years. The world's largest producer is China followed by India and the USA with 30, 11 and 8%, respectively (CGSIN, 2018). The other producers, with figures above 5 million tons, were Turkey, Egypt, and Iran. The current average worldwide is 35 $t \cdot ha^{-1}$, but the highest production per area is in European greenhouses, where it can exceed 700 $t \cdot ha^{-1}$ in a season. A crop of fresh tomatoes in the open field and with high production with furrow irrigation, normally produces between 50 and 70 $t \cdot ha^{-1}$ (CGSIN, 2018).

Tomato cultivation in Ecuador is of utmost importance, being a staple product in the basic family basket and of great value for the country's agriculture. According to the Food and Agriculture Organization of the United Nations (FAO), in 2017, 62,675 tons of fresh tomato were produced in Ecuador (FAO, 2017). On the other hand, the General Coordination of the National Information System stated that there were 1,954 hectares planted with table tomato in Ecuador. With these data, it was obtained that the average yield of table tomato in Ecuador was 32.08 t·ha-1 and is below the average yield of other countries (CGSIN, 2018).

The most important provinces for table tomato production are Imbabura, Cañar, Chimborazo, Cotopaxi, Tungurahua, Santo Domingo de Los Tsáchilas, Santa Elena, Carchi and Loja, among others, according to the National Institute of Statistics and Census (INEC, 2021). In the highlands, there is a need to grow tomatoes under greenhouses because of the temperature requirements. This product is of great importance in Ecuadorian society.

The per capita consumption of table tomato in Ecuador was 6.8 $kg \cdot person^{-1}$ in 2017 and is expected to increase due to new food trends (CGSIN, 2018). Considering that this figure was also low compared to other South American countries; however, tomato is a food that is part of the basic food basket; being, also highly vulnerable to price fluctuations. Indicating also, that the agri-food industry has developed a large number of products made from tomato for which abundant and high-quality raw material is needed, since, for processed tomato foods, it is not possible to cover the national demand, so it is necessary to import from neighboring countries goods with added value, which harms Ecuador's trade balance (CGSIN, 2018).

One of the fundamental factors in seedling production is the use of substrates that are suitable for the conditions of a production system. In the selection of these substrates, the physical (Blok and Wever, 2008), chemical (Pastor, 1999), and biological characteristics must be considered, according to the type of product to be generated. These characteristics are important to maximize the efficiency of fertirrigation strategies and reduce the effect of containers (trays) such as the presence of small water reservoirs and drainage difficulties (Richmond, 2010). Commercial peat-based substrates are easy to obtain in peat-producing countries; however, the importation of these materials generates significant increases in production costs. Therefore, the search for alternatives to substitute this material, which is easy to obtain for the production system, is transcendental. For the development of substrates, the cost should be taken into account and preferably the raw materials should be from the area (Garbanzo and Navarro, 2015). In addition to low cost, a substrate should be easy to handle, inert, and provide a low environmental impact (Tombion et al., 2016).

Agriculture is oriented to the achievement of high yields and quality at the lowest cost, for which seeds with excellent genetic and biological characteristics are needed, where crops such as tomato require seedbed, it is necessary to provide optimal conditions for seedling development, which is essential to ensure the quality and health of the plant until the production stage, in addition to adequate physical and chemical conditions of the substrate (Soto and Ramírez, 2002). Therefore, the objective of this research was to evaluate the emergence and initial growth

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of tomato seedlings (Solanum lycopersicum L.) in different substrates.

Methodology

The research was carried out in the facilities of the Maranatha Educational Unit, in El Carmen Canton, Province of Manabí, Ecuador, in a place with a shed and abundant light; located at 0º15' S, 79º26' W, 260 mamsl, in a humid tropical climate, temperature 24 °C, relative humidity 86%, 1,026 hours of light·year^{1} and precipitation of 2,806 mm·year^{1}.

Culture or seed trays were used, which were made of expanded polystyrene with 50 cells, with a volume of approximately 300 cm^{3}. The tomato seeds used were of the Floradel variety. Three treatments were established, which were made up of three substrates: agricultural soil (black soil, T1), cocoa crop residues (cocoa soil, T2), and wood cutting residues (sawdust, T3), with three replicates and each replicate with 50 seeds per tray, arranged in a completely randomized block treatment design, each tray corresponded to a treatment.

The variables evaluated during the development of the research were: seedling emergence expressed in percentage, for this they were considered as emerged plants, those whose cotyledon leaves were on the surface of the substrate, the emergence percentage was determined by counting the number of seedlings that emerged in relation to the total number of seeds used in the experimentation for each substrate, where the percentage of emergence= (number of seedlings emerged)/(number of seeds sown) x 100 and the height of the seedlings measured in cm with a ruler from the base of the soil to the last expanded leaf, it began 12 days after sowing, it was carried out twice a week (between 3 and 4 days) and at the end of the investigation the diameter of the stem was measured with a vernier in mm, at a height of 5 cm from the substrate, the last evaluation was carried out 30 days after sowing, when the seedlings were already in good conditions to be transplanted; both the height and the diameter of the stem were evaluated in all the seedlings that emerged and developed in each of the substrates.

Statistical analysis was performed with SAS University Edition software (SAS, 2020) and Tukey's test ('P-value= 0.05') was used to detect differences between averages. Due to the seedling emergence variable did not meet the assumption of normality, a square root transformation was performed and the resulting values were used as the response variable; to test normality, the Q-Q plot constructed with the residual values was used (Montgomery, 2003).

The length of the seedlings was analyzed using the methodology of repeated measures over time through the MIXED procedure (SAS University Edition); second-degree polynomial models that best explained the behavior of this variable were selected.

Results

Statistical differences were found in the variables studied ('P-value= 0.01'). In all cases, the substrate that presented the highest values for all variables was black soil (T1), followed by cocoa soil (T2), and finally sawdust (T3).

There were statistical differences ('P-value= 0.001') between the three substrates evaluated for seedling emergence, the highest percentage of this variable was observed with cocoa soil (83.33%), followed by black soil (72.67%) and lastly sawdust with 61.33%. The average seedling emergence was 72.44% (Figure 1). This represented that in cocoa soil the percentage of seedling emergence was 1.15 and 1.36 times higher than in black soil and sawdust, respectively; while in black soil it was 1.18 times higher than in sawdust.

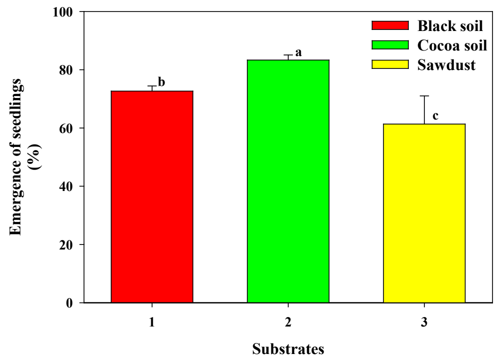

Figure 1. Emergence percentage of tomato seedlings growing in three substrates and under a shed in El Carmen, Manabí, Ecuador.

It is important to highlight that 12 days after the start of the trial, the seedlings growing in the black soil (T1) and cocoa soil (T2) were between 2.1 and 2.2 cm, while the seedlings growing in the sawdust were 1.23 cm, it was noted that the seedlings growing in the black soil reached the greatest height (Figure 2).

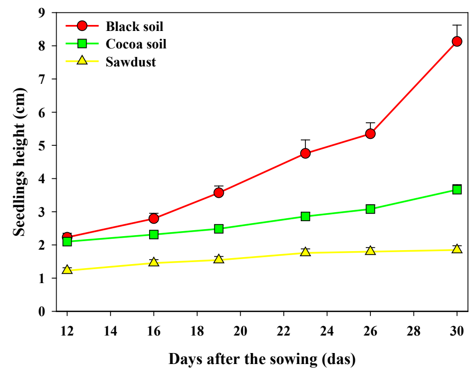

Figure 2. Height of tomato seedlings growing in three substrates and under a shed in El Carmen, Manabí, Ecuador.

When starting the seedling length evaluations (12 days after planting; das), there were no statistical differences between treatments (‘P-value= 0.05’; Table 1). At 16 das, the greatest was presented in the seedlings that grew in the black soil substrate and the least in those that grew with sawdust (Figure 2). There were no significant statistical differences between the seedlings that grew in black soil (T1) and cocoa soil (T2; ‘P-value= 0.05’), whose average was 2.55 cm; while there were statistical differences between these two treatments indicated above, and the seedlings that grew in sawdust (T3; ‘P-value= 0.01’; Table 1). This behavior was similar at 19 das (Table 1).

Table 1. Tukey’s means test of the height of tomato seedlings growing in three substrates under shed conditions in El Carmen, Manabí, Ecuador.

	Days after sowing (dds)					
Treatments	12	16	19	23	26	30
Black soil (T1)	2.23 a	2.79 a	3.57 a	4.47 a	5.35 a	8.13 a
Cocoa soil (T2)	2.10 a	2.31 a	2.49 a	2.86 b	3.08 b	3.66 b
Sawdust (T3)	1.22 a	1.46 b	1.54 b	1.76 bc	1.80 c	1.85 c

Means with different letters in the rows presented significant differences according to Tukey's multiple range test (‘P-value= 0.05’).

From 23 to 30 das, statistical differences (‘P-value= 0.01’) were found among the three treatments evaluated, except at 23 das where the seedlings that grew in cocoa soil and sawdust did not present statistical differences (‘P-value= 0.05’, on average with 2.31 cm of height of the seedlings). At 30 days after sowing, the seedlings that grew in black soil reached a length of more than 8.13 cm; by the same time, the seedlings that grew in cocoa soil reached a length of about 3.66 cm and those grown in sawdust reached about 1.85 cm, which showed that the black soil was more suitable for the growth of tomato seedlings (Figure 2).

In this sense, when comparing the length of seedlings that grew in black soil with sawdust at 12, 16, 19, 23, 26 and 30 das, this was 1.83; 1.91; 2.32; 2.70; 2.97, and 4.39 times greater, respectively. When the same comparison was made between the length of seedlings that grew in black soil and those sown in cocoa soil, the differences were 1.06; 1.21; 1.43; 1.66; 1.74, and 2.22 times greater in black soil, respectively, for the same days evaluated.

When comparing the seedlings that grew in cocoa soil with sawdust, for the same samplings, it was found that the seedlings that grew in cocoa soil were 1.72; 1.58; 1.62; 1.63; 1.71, and 1.98 times greater than those grown in sawdust (Table 1), this suggested that the seedlings grown in black soil, could be in conditions for transplanting in less time.

The statistical analysis of repeated measures over time for this trial generated second-degree polynomial equations ($Y= a + bx + cx^2$) that explained the behavior of the seedling length as a function of time variable. The equations generated were:

$$T1= 3.8386 - 0.3009 \times days + 0.0146 \times days^2$$

$$T2= 2.1183 – 0.0346 \times days + 0.0028 \times days^2$$

$$T3= 0.2495 + 0.0992 \times days - 0.0015 \times days^2$$

There were statistical differences (‘P-value= 0.003’) for the stem diameter variable due to the effect of the substrates used. The seedling that grew in black soil reached a stem diameter of 2.45 mm 30 days after sowing, those in cocoa soil 1.31 mm, and those in sawdust 0.61 mm, which corresponds to the trend that the length of the seedlings presented (Figure 3).

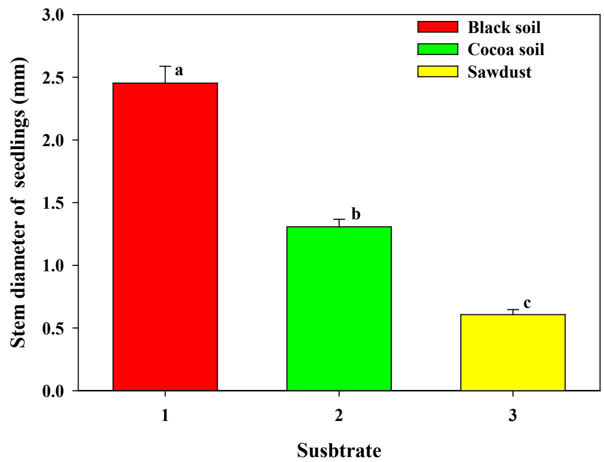

Figure 3. Stem diameter of tomato seedlings growing in three substrates and under a shed in El Carmen, Manabí, Ecuador.

The stem diameter of seedlings that grew in black soil was 1.87 and 4.02 times greater than those that grew in cocoa and sawdust soil, respectively. For those that grew in cocoa soil, it was 2.15 times greater than those that grew in sawdust.

Discussion

The selection of the substrate is transcendental for plants, since it provides the appropriate conditions for the crop for root anchorage, plant growth, and development (Ocampo et al., 2005; Caballero-Salinas et al., 2020). For Baskin and Baskin (2001), the response of seedling emergence is related to the environmental conditions offered to the seeds for their germination and subsequent emergence from the substrate.

In this sense, the results found in this research corroborated this assertion, since in the substrates of black soil and cocoa soil the percentage of emergence (72.67 and 83.33%), the height

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(8.13 and 3.66 cm), and the diameter of the stem (2.45 and 1.31 mm), respectively; was higher than that presented in sawdust (61.33%, 1.85 cm and 0.61 mm, respectively), which suggested the presence of less favorable conditions for seedling growth and development in sawdust.

It should be noted that the characteristics of the substrate (texture, structure, porosity, among others) play a preponderant role in the emergence of the seedlings, since in their process of crossing and emerging to the soil surface, they must overcome physical barriers imposed by the substrate in which they are; in other words, the seeds can germinate, but if the substrate conditions are adverse, they will not be able to emerge from the soil.

The research conducted by Garbanzo-León and Vargas-Gutiérrez (2017) where they evaluated the germination of tomato seeds in a germination chamber using different substrates (50% compost + 25% sand + 25% solarized soil, 50% vermicompost + 25% compost + 25% coconut fiber, 50% vermicompost + 25% sand + 25% solarized soil, 50% bokashi + 25% vermicompost + 25% vermicompost + 25% sand + 25% solarized soil, 50% bokashi + 25% vermicompost + 25% compost + 25% coconut fiber and 50% bokashi + 25% sand + 25% solarized soil) determined that all the germination percentages, in whose mixtures 50% bokashi was placed as a base, showed problems in germination and this decreased up to 20%, the same when compared with the other mixtures; which corroborates that germination and seedling emergence can be affected by the type of substrate used.

In this same order of ideas, Godínez-Ibarra et al. (2007) and Nolasco-Guzmán et al. (2016) indicated that seedling survival was not guaranteed by seed germination and emergence, because seeds can be affected by diseases, adverse environments, substrate compaction or consumed by herbivores.

In this research, regarding the percentages of seedling emergence obtained for the various substrates (83.33% for cocoa soil, 72.67% in black soil, and 61.33% in sawdust), even though the cocoa soil had the highest percentage of emergence, it did not achieve the greatest growth and development of the seedlings.

Ortega-Martínez et al. (2010) using peat, sawdust, vermicompost, agricultural soil, and peanut shells as substrates found seedling emergence between 90 and 12%. The emergence of seedlings in sawdust was 80% and in agricultural soil 15%, results that contrast with those obtained in this research, where in its equivalent the black soil presented an emergence of 72.67% and 61.33% sawdust, evidently these differences could be attributed to the chemical composition of the black soil and the type of wood from which the sawdust was obtained.

On the other hand, the results obtained in this research coincided with those of Meng et al. (2018), who indicated that tomato seedlings had different growth depending on the substrate in which they were germinating.

In this research, it was evidenced that the substrate that favored the greatest growth of seedlings was black soil and the lowest growth was presented in sawdust, results that coincided with those indicated by Favaro et al. (2002) using as substrates sawdust of Salix sp. alone and mixed with perlite (0, 25 and 75%) or with peat and perlite (33% of each) when cultivating tomato (*S. lycopersicum*) and Caballero-Salinas et al. (2020) when growing tree tomato (*Physalis ixocarpa* Brot.) with cosmopeat, vermicompost, *Pinus oocarpa* sawdust and compost, in both cases under shed conditions, and pointing out that the lowest growth in sawdust could be attributed to the low nutrient supply and moisture retention that this substrate offers.

Therefore, Caballero-Salinas et al. (2020) suggested the need to initially supply macro and micronutrients to the seedlings to increase growth; in addition to subjecting the sawdust to a pre-composting process. It was also noted that even though the greatest emergence occurred in the cocoa soil, the seedlings that grew in the black soil showed the greatest development. With the black soil during all the samplings carried out in the research, the length of the seedlings was greater than in the cocoa soil and when grown in sawdust.

It is important to indicate that even though there is abundant scientific information on the use of organic substrates for the growth of various plant species, in particular on the use of black soil, cocoa soil and sawdust was scarce; however, given the fact that in the study area, these substrates are found in abundance, they were used, at the same time it was necessary to make some comparisons with other organic substrates used for seed germination.

Garbanzo-León and Vargas-Gutiérrez (2017) pointed out that in the mixtures with organic substrates the seedlings presented greater growth and development than those that were growing with peat moss (sphagnum moss). In the same sense, Richmond (2010) found that adding organic compost to the substrate mixtures improved the growth of tomato seedlings. Even though they were not the same substrates used in this research, what stands out is that organic substrates have a marked influence on plant growth and development.

The obtaining of vigorous tomato seedlings allows reducing the loss of plants after transplantation, in addition to this, there is the alternative of using substrates available in the producing regions of the species, which guarantees a lower cost of production of the seedlings, this could be influenced by the nutritional contribution offered by the black soil and cocoa soil, which generated a greater development in the length and diameter of the stem of the seedlings.

Ortega-Martinez et al. (2010) pointed out that tomato seedlings that grew under greenhouse conditions using composted pine sawdust (*Abies religiosa*), ground pericarp ('hulls'), agricultural soil, and vermicompost as substrates, and the commercial mixture of Dutch peat (Sunshine registered brand® sun gro Horticulture. Inc) as a control treatment, obtained the greatest height with vermicompost (17 cm) and peat (15 cm), followed by those that grew in sawdust (12 cm), measured at 30 das.

This fact indicates that seedling growth and development were favored by substrates with sufficient nutrients. The seedlings that were taller also had a greater percentage of emergence and germination, which can be particularly attributed to the characteristics of the substrate and the few nutrient reserves of the seeds. In this research, the plants that grew in sawdust had limited growth (1.85 cm). Perhaps some compounds present in the sawdust inhibited the development of the seedlings.

This suggests that the plants grown in sawdust, given the small height of the seedlings and the thin diameter of the stem, could be presenting adaptability problems at the time of transplantation. In general terms a quality seedling is identified by a vigorous stem, the thickness of the stem is commonly related to the hardness of the seedling; that is, a stem with more than 3 to 5 mm is adequate at the time of transplantation (Casanova et al., 2003; Torres Rodríguez et al., 2016; Chiquito-Contreras et al., 2017; 2018; 2020).

Conclusions

The substrates studied showed different effects on the development and growth of tomato seedlings. The black soil generated the greatest development of the tomato seedlings, since they presented the greatest height and diameter of the seedlings, although they did not have the greatest emergence. Sawdust was the substrate with the lowest emergence, height, and diameter of seedlings.

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Conflict of interest

The authors declare that they have no conflict of interest in this publication at any stage.

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Authors' contribution

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Leonardo Enrique Avellán-Vásquez	Research supervision, data interpretation and manuscript content review, manuscript content review.
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