

Effect of a turmeric-based fertilizer on tomato production at green-house level

Efecto de un fertilizante a base de cúrcuma sobre la producción de tomate en invernadero

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ABSTRACT

Inorganic fertilizers have impacts on the availability of nutrients and the content of organic matter in the soil, as well as on its native microbiota. A turmeric fertilizer (TF) with added food residues and wood ashes was developed to evaluate its effects on tomato production and crop soil properties. The TF was prepared by emulsion technology using three turmeric concentrations expressed as 1.0, 2.5 and 3.0 % w/v; it was characterized according to its rheological (apparent viscosity, consistency and flow behavior indexes) and physical (z-average droplet size) characteristics. Nitrogen, phosphorus and potassium (NPK) levels and moisture-holding capacity were measured in crop soil. Colour, soluble solid content, acidity, diameter and the number of tomatoes were evaluated. The photosynthetic index of the leaves of tomato plants was determined. It was observed that when turmeric concentration increased (> 1.0 % w/v), the droplet size decreased enhancing the physical stability of TF. NPK levels and moisture-holding capacity of the soil improved, especially with turmeric concentrations > 1.0% w/v. Positive effects on the tomato fruit properties (soluble solid content, acidity, diameter and tomato number) and photosynthetic index of tomato plant leaves were observed with turmeric concentrations of 2.5 and 3.0 % w/v. The TF positively influenced the crop soil and the metabolic process of the tomato plants, and the characteristics of its fruits.

RESUMEN

Los fertilizantes inorgánicos afectan la disponibilidad de nutrientes, el contenido de materia orgánica en el suelo y su microbiota nativa. En este trabajo se desarrolló un fertilizante de cúrcuma (TF) adicionado con residuos alimenticios y cenizas de madera, para evaluar sus efectos sobre la producción de tomate y propiedades del suelo. El TF se preparó mediante tecnología de emulsión utilizando tres concentraciones de cúrcuma (1.0, 2.5 y 3.0 % p/v), y se midieron sus características reológicas (viscosidad aparente, e índices de consistencia y comportamiento de flujo) y físicas (tamaño de gota z-average). Se midieron los niveles de nitrógeno, fósforo y potasio (NPK), y la capacidad de retención de humedad en el suelo. Se evaluaron el color, contenido de sólidos solubles, acidez, diámetro y número de tomates. Se determinó el índice fotosintético en las hojas de la planta. Se observó a medida que aumentaba la concentración de cúrcuma (> 1,0 % p/v), una disminución del tamaño de las gotas, mejorando la estabilidad física del TF. Los niveles de NPK y la capacidad de retención de humedad del suelo mejoraron, especialmente, con concentraciones de cúrcuma > 1,0 % p/v. Se observaron efectos positivos sobre los tomates (contenido de sólidos solubles, acidez, diámetro y número de unidades) y en el índice fotosintético de las hojas de la planta con concentraciones de cúrcuma de 2,5 y 3,0 % p/v. El TF influyó positivamente sobre el suelo y el proceso metabólico de las plantas, así como en las características de sus frutos.

Palabras clave: Capacidad de retención de humedad, nivel de NPK, índice fotosintético, propiedades reológicas, características físicas

Research highlights

- The turmeric fertilizer improved the moisture-holding capacity and NPK levels of soil.
- The photosynthetic response was positively affected by the turmeric fertilizer.
- The quality and yield of treated tomato plants with turmeric fertilizer were improved.

INTRODUCTION

Low fertility soils are a common problem in many regions of the world (El-Naggar *et al.*, 2019). According to the Food and Agriculture Organization of the United Nations, 25 % of the world's agricultural land shows signs of erosion (FAO, 2011). Intensive agricultural practices and the rise in global temperature of the planet due to climate change can aggravate soil degradation, threatening soil functionality and productivity (Antoniadis *et al.*, 2017) and leading to nutrient depletion and reduction of the natural microbiota in the soil (Ramírez-Gil *et al.*, 2013). Consequently, the soil becomes susceptible to being colonized by pathogens, causing the decline of many commercially important fruits and root crops (Cano, 2011).

Inorganic fertilizers are used for the treatment of infertile soils (Álvarez-Hernández *et al.*, 2011). However, their long-term application might have a serious impact on the availability of nutrients and organic matter content in the soil, as well as on its native microbiota (Salamat *et al.*, 2021). Therefore, natural and economical solutions that can contribute to improving soil fertility without negative side effects on soil and crops are needed (Shaheen *et al.*, 2013). Organic fertilizer production is based on using organic sources to provide necessary plant nutrients such as compost and other animal and plant wastes. However, managing to meet the nutrient requirements needed in crops using only organic sources is a major challenge (Bergstrand, 2022). Organic production systems are usually associated with lower productivity than conventional systems, therefore, a current challenge is to develop an organic fertilizer that maintains an adequate supply of nutrients to the soil and therefore to the plantations.

Studies conducted with organic fertilizers have shown the growth of leaves and the increased height and width of shoots in mustard crops (Kai and Tamaki, 2020). The use of organic fertilizers in apple cultivation allowed an improvement in nutrient levels and microbial activity in soils (Kai and Kubo, 2020; Kai and Adhikari, 2021). Another study on cherry tomatoes showed that the use of a natural fertilizer positively affected the crop (larger and heavier fruits with higher lycopene content), as well as the soil properties (increased nutrient content, microbial activity, and biomass) (Kai *et al.*, 2020). An important aspect to

consider when using organic fertilizers is their ability to reduce crop infections. Among the bioactive compounds with antimicrobial and insect repel activities is turmeric (Reganold *et al.*, 2001). Upendra *et al.* (2011) reported the inhibitory activity of turmeric powders against fungal contaminations in plant tissue culture. A recent study reported that curcumin (the primary active compound in turmeric) exhibited a broad-spectrum antimicrobial activity (antiviral, antibacterial, antifungal, and antimalarial activities), emphasizing its ability to prevent and control endophytic and latent contamination in apple crops (Kai and Adhikari, 2021). Therefore, the objective of this research was to develop a turmeric fertilizer with added food residues and wood ashes, and to evaluate its effect on tomato production and crop soil properties.

MATERIALS AND METHODS

Materials

Turmeric and whole milk were purchased from a local market in the city of Osorno, Chile. Coffee bean residues, banana peel and wood ash were collected from local consumption in the city of Osorno. Tomato plants of the *Cal ace* variety were used.

Experimental planting conditions

Tomato plants ($n = 12$) of the *Cal ace* variety were grown in a greenhouse (8 m²) next to the Universidad del Bío-Bío, Chillán, Chile, located at the western longitude of $-72^{\circ} 4'$, and the southern latitude of $-36^{\circ} 36'$. The early tomato plants were sown on December 2021, transplanted on January 2022 and then tomatoes were harvested at the end of April 2022 when the average minimum and maximum air temperatures were 11.9 ± 1.6 °C and 27.8 ± 3.6 °C, respectively. The average relative moisture in the air was 53.5 ± 4.5 %, and the average daylight was approximately 12.8 ± 1.4 h. Soil moisture was adjusted to 25.6 ± 2.4 % (wet basis) during the analysis, and soil pH remained constant at 5.8 ± 0.2 because according to Kyomuhendo *et al.* (2020), pH values above or below the range pH 5.8 to 6.5 may result in less vigorous growth and nutrient deficiencies.

Experimental design for fertilizer preparation

Turmeric (1.0, 2.5 and 3.0 % w/v) was dissolved with moderate agitation in whole milk at 40°C for 1 h, using an adjustable high-speed homogenizer (FK-FSH-2A Model, MXBAOHENG, China) to obtain a colloidal emulsion type mixture. The collected residue of coffee beans was drained, ground and diluted in distilled water (0.19 % w/v). Banana peels were chopped, ground and diluted in water (0.44 % w/v). Wood ashes were

sieved (mesh opening of 2 mm) and diluted in water at 3.29 % w/v. Nitrogen content was determined following the standards of the National Institute of Standardization (National Institute of Standardization, 2002), phosphorus using the AOAC standard (2019), and potassium using the AOAC standard (2012). Subsequently, the food residue solutions (coffee beans and banana peels) and wood ash solution were mixed to obtain a [nitrogen: phosphorus: potassium] ratio of [(15: 4: 20) (mg kg⁻¹: mg kg⁻¹: mg kg⁻¹)] with a [total organic carbon/nitrogen] coefficient lower than 10 (dimensionless value) in the resulting mixture, which was mixed with the initially prepared turmeric emulsion. The resulting product was called turmeric fertilizer (TF), and three turmeric concentrations (1.0, 2.5 and 3.0 % w/v) were studied. Therefore, the doses of the active ingredient per mass of product were 10, 25 and 30 g of turmeric per kg of TF. One diluted sample of 200 mL TF [7 g TF / 200 mL water] was added to each tomato plant in the transplanted stage. The 12 plants studied were divided into 4 blocks, 3 control plants without fertilizer treatment, and 3 plants for each turmeric fertilizer treatment (1.0, 2.5 and 3.0 % w/v).

Fertilizer characterization

Rheological behavior. The rheological behavior of fertilizer was evaluated with a strain and stress-controlled rheometer (Physica MCR 300, Anton Paar, Filderstadt, Germany). The instrument was equipped with two smooth parallel plates (50 mm diameter). The gap between the plates was 0.8 mm. The temperature was kept constant at 25 °C, with an accuracy of 0.1 °C, during the measurements by using a water bath connected to the Peltier system. The apparent viscosity (η_{app}) was determined at a shear rate of 0.3 s⁻¹ from flow curves by varying the shear rate between 0.01 and 1 s⁻¹. The data were fitted to Power Law and Herschel-Bulkley models (US200 Physica version 2.01, USA) to obtain the rheological parameters consistency index (k), flow behavior index (n), and yield stress (σ_0) (Mezger, 2002). The analysis was performed in triplicate with six replicates for each sample. During the analysis, a commercial seaweed-based organic fertilizer was used as a control.

Droplet size and droplet size distribution. The droplet size (expressed as z-average) and droplet size distribution were measured by dynamic light scattering (DLS) using a Zetasizer Nano ZS equipment (Malvern Instruments Ltd., Worcestershire, UK). The Zetasizer equipment operated with a 633 nm He-Ne laser using back-scattering detection (173°). The droplet size measurement was based on the analysis of laser scattering fluctuations due to the droplet's Brownian motion; average droplet size was determined using the Stokes-Einstein relationship. Measurements were recorded at

25 °C after an equilibrium period of 45 s (Leiva-Vega *et al.*, 2020). Tests were performed in triplicate and the results represented the average of nine readings. The refractive index and absorption index of the oil phase were 1.5 and 0.001, respectively, and the refractive index and dielectric constant of water were 1.33 and 78.5, respectively. During the analysis, a commercial seaweed-based organic fertilizer was used as a control.

Soil characterization

Nitrogen, phosphorus, and potassium levels. The soil used for tomato planting was characterized by measuring nitrogen (N), phosphorus (P), and potassium (K) levels using a soil nutrient sensor (Soil Nutrient Detector, Chengdu Sentec Technology Co., Sichuan, China). The technique is based on the conductivity measurement of steel electrodes that were immersed in the moist soil samples (25.6 ± 2.4 % wet basis), and the variability in electrical conductivity was expressed as N, P and K levels (Longhurst and Nicholson, 2010; Kulkarni *et al.*, 2014). Measurements were taken every 5 days for 100 days after planting tomato plants, using soil without added fertilizer as control.

Moisture-holding capacity. The moisture-holding capacity (MHC) was determined according to the methodology of Bejar-Pulido *et al.* (2020), with some modifications. The soil added with the fertilizer (1, 2.5 and 3 % w/v TF) was dried at 25°C for 16 h using a solar dryer and sieved (mesh opening of 2 mm). The dehydrated soil sample (100 g) was placed on a plate and moistened in average ambient conditions (at 14.6 ± 6.8 °C for 12 h, with relative humidity of 66.5 ± 9.2 %). The moisture content was determined gravimetrically (105 °C for 24 h) in triplicate. Moisture-holding capacity was determined using Equation 1. The control was soil without added fertilizer.

$$MHC \left(\frac{g \text{ H}_2\text{O retained}}{100 \text{ g of dry soil}} \right) = \frac{(PW + Pws) - (PW + Pds)}{(PW + Pds) - (PW)} \times 100 \quad [1]$$

where: PW, Pws, and Pds is the weight (g) of the plate, wet soil, and dry soil, respectively.

Tomato characterisation

Colour values. The tomato colour was expressed in terms of the CIELab scale: L^* (from white to black), a^* (from green to red), and b^* (from blue to yellow) (Spricigo *et al.*, 2021); it was measured using a digital colorimeter spectrophotometer (LS170, Linshang Technology Co, Shenzhen, China) calibrated with a standard white ceramic plate ($L^* = 96.29$, $a^* = 0.4^*$, $b^* = 3.14$). The total colour difference (ΔE^*) was calculated as the difference between tomatoes obtained from plants treated with

TF, and tomatoes obtained from plants without fertilizer added as control, according to Equation 2. Twelve measurements were made for each tomato in triplicate.

$$\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \quad [2]$$

where: ΔL^* represents a lightness difference, Δa^* represents a redness or greenness difference, and Δb^* represents a blueness or yellowness difference.

Soluble solid content and pH value. The soluble solid content of tomatoes was measured using a digital refractometer (HI-96801, Hanna Instruments, Tokyo, Japan); the tomato homogenate was filtered with gauze and dripped on the measuring cell (Ayusto-Yuste et al., 2022). The pH was measured using a digital benchtop pH meter (Piccolo, Hanna Instruments, Tokyo, Japan) following the methodology described by Astuti et al. (2018). For both analyses, twelve measurements were made for each tomato in triplicate using tomatoes from plants without fertilizer added as control.

Diameter and tomato number. Tomato diameter was measured with a metric Vernier calliper, and measurements were made in triplicate with 4 replicates in each case. In parallel, the tomato number per plant was counted. Both measurements were performed 100 days after the transplanted stage. Tomatoes from plants without fertilizer added were used as control.

Photosynthetic index

The photosynthetic response of tomato plant leaves was estimated using a photosynthetic index proposed in the methodology of Kovačević et al. (2015) but based on spectral pictures analyzed with the Omsi-M software. The sampling time was 100 days after the transplanting stage and five images were taken per plant using 3 plants from each treatment. The control consisted of leaves of tomato plants cultivated in soil without added fertilizer.

Statistical analysis

Results were evaluated by analysis of variance and significant differences between the mean values ($p < 0.05$) were determined using Tukey’s test. The results were reported as the mean value \pm standard deviation.

RESULTS AND DISCUSSION

Fertilizer characterization

Rheological behavior. Rheological behavior is a key property of emulsions ranging from highly non-Newtonian viscoelastic products to mobile Newtonian liquids (Zhu et al., 2020). Figure 1 shows the apparent viscosity of the turmeric fertilizer (TF) as a function of shear rate. Viscosity showed a decreasing trend from 188.05 to

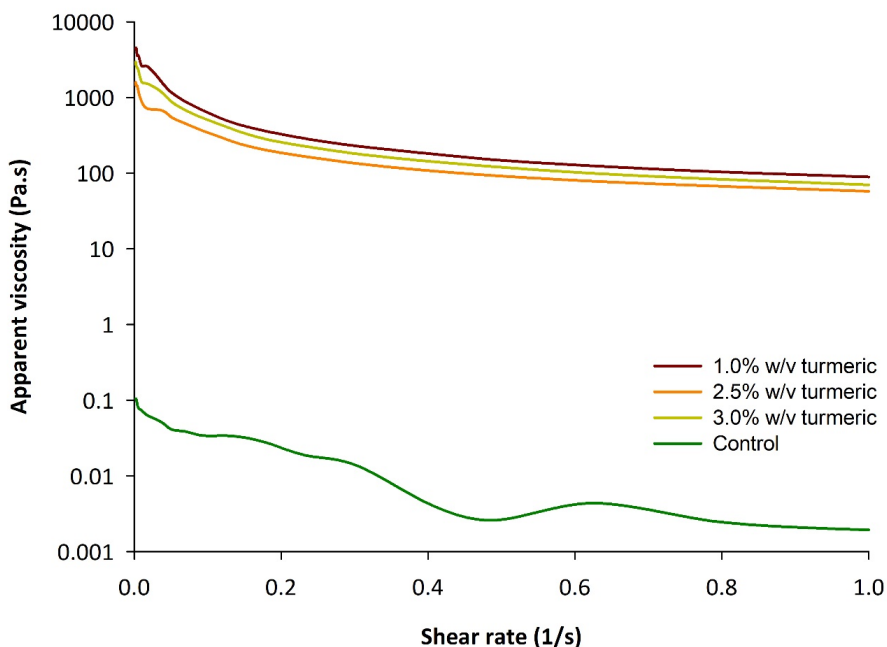


Figure 1. Apparent viscosity for the turmeric fertilizer with 1.0, 2.5 and 3.0 % w/v turmeric. The control was a commercial fertilizer.

Figura 1. Viscosidad aparente para el fertilizante de cúrcuma con 1,0, 2,5 y 3,0 % p/v de cúrcuma. El control fue un fertilizante comercial.

111.25 Pa.s as curcumin concentration increased from 1.0 to 3.0 % w/v, although viscosities of the TFs were clearly higher than the viscosity of the control (a commercial fertilizer) (Fig. 1). The high viscosity of the TFs was explained because the fertilizer samples were prepared as emulsified systems concentrated in particles, from coffee beans, banana peels and wood ashes. The lower viscosity in the samples containing 1.0 and 2.5 % w/v turmeric could have been due to the partial coverage of particles, allowing their mobility. When turmeric concentration was 3.0 % w/v, the viscosity increased probably due to a covering and hampering of particle mobility (Hong *et al.*, 2018).

Table 1 summarizes the rheological character of the TFs using the Power law and Herschel-Bulkley models. The determination coefficient (R^2) method was selected to find the best-fit model. High determination coefficients ($R^2 > 0.97$) were obtained with the Herschel-Bulkley model. Yield stress (s_0) indicates that the applied effort to achieve fluidity ranged between 2.60 and 3.49 Pa for the fertilizer samples; the values were higher than the value exhibited by the control (0.13 Pa) indicating that the fertilizer samples require more effort to achieve fluidity. This finding could suggest the presence of interactions between emulsion droplets in the studied range of yield stress (2.60 Pa to 3.49 Pa) (Simon *et al.*, 2010). The consistency index (k) represents the viscous nature of an emulsion, and its higher values reflect higher viscosity (Zhu *et al.*, 2020). As occurred with the apparent viscosity, the k value decreased when turmeric concentration increased, but the values were higher than the value of the control. This behavior was consistent with the results reported by Ma

et al. (2017); the authors observed that the addition of curcumin led to higher viscosities in comparison to the control but decreased the emulsion stability. The fertilizer samples displayed non-Newtonian shear-thinning behavior, meaning that turmeric did not change their flow behavior ($n=1$) (Ilyin *et al.*, 2015). For a typical non-Newtonian shear-thinning emulsion, a disruption behavior of floc structures at a high shear rate is frequent (Sheng *et al.*, 2018). Non-Newtonian shear-thinning behavior is typical of emulsions having dispersed particles such as small particles of plant tissue (Sheng *et al.*, 2018). Therefore, the fertilizer samples could exhibit a breaking behavior of flocculated droplets with the increase of shear rate, contributing to the dispersion of their droplets.

It is important to establish that fertilizer viscosity is critical to reduce leaching losses in the soil. In the case of the present formulation, the addition of polymeric materials and turmeric to the different formulations reduces the loss of nitrogen in the soil and therefore increases the absorption of this nutrient by the plants. In addition, subsequent tests on tomato crops showed that the fertilizer formulations, when compared to the control, present a greater viscosity that contributes to reducing the loss of nutrients and moisture in the soil (Mikkelsen *et al.*, 1993).

Droplet size and droplet size distribution. Droplet size is one key property that affects the physical characteristics of an emulsion, such as rheology and stability (McClements, 2016). Fig. 2 shows the effect of turmeric concentrations on the droplet size of TFs. The use of whole milk as an emulsifier probably promoted the so-

Table 1. Rheological parameters from the Power Law and Herschel-Bulkley models for the turmeric fertilizer with 1.0, 2.5 and 3.0 % w/v turmeric. The control was a commercial fertilizer.

Cuadro 1. Parámetros reológicos de los modelos de Ley de Potencia y Herschel-Bulkley para el fertilizante de cúrcuma con 1,0, 2,5 y 3,0 % p/v de cúrcuma. El control fue un fertilizante comercial.

	Rheological parameters							
	η_{app} (Pa.s)	Power Law $s = kg^n$			Herschel-Bulkley $s = s_0 + kg^n$			
(% w/v)		k (Pa.s ⁿ)	n	R^2	s_0 (Pa)	k (Pa.s ⁿ)	n	R^2
1.0	188.05 ± 9.19 ^d	112.46 ± 8.72 ^d	0.37 ± 0.01 ^b	0.89	3.49 ± 0.27 ^d	1419.35 ± 24.21 ^b	0.02 ± 0.001 ^b	0.99
2.5	111.25 ± 12.72 ^b	62.14 ± 12.47 ^b	0.37 ± 0.03 ^b	0.90	2.60 ± 0.18 ^b	1013.58 ± 54.14 ^c	0.01 ± 0.000 ^a	0.98
3.0	148.08 ± 16.97 ^c	76.71 ± 8.77 ^c	0.38 ± 0.04 ^b	0.89	3.21 ± 0.79 ^c	1228.06 ± 71.13 ^d	0.01 ± 0.000 ^a	0.98
Control	0.014 ± 0.004 ^a	0.58 ± 0.04 ^a	0.11 ± 0.01 ^a	0.87	0.13 ± 0.04 ^a	0.98 ± 0.25 ^a	0.01 ± 0.001 ^a	0.97

where: η_{app} is apparent viscosity, s is shear stress, s_0 is yield stress, k is consistency index, g is shear rate, and n is flow behavior index. R^2 is the determination coefficient. Values are means ($n = 7$) ± SD. SD represents the variability of the samples. Different superscript letters in the same column indicate significant differences ($p < 0.05$).

lubilization of turmeric; thus, contributing to the reduction of the droplet size compared to the control, which was a commercial fertilizer without turmeric. Specifically, increasing the turmeric concentration from 2.5 to 3.0 % w/v resulted in a 29 % decrease in droplet size (from 570 nm to 403 nm). This behavior could be attributed to two main mechanisms: (i) enough dairy emulsifier molecules to cover a larger droplet surface, and (ii) the available dairy emulsifier molecules can cover the droplet surface more rapidly, which leads to a re-

duction in droplets coalescence (Dahlawi *et al.*, 2020). The droplet size distributions in Fig. 3 also confirmed that the dairy emulsifier led to small droplet sizes and a narrow droplet size distribution for the studied turmeric concentrations. These results also showed that the droplet size distribution for the control was much wider. In addition, the fact that the particles are homogeneous and small helps with the occurrence of higher nutrient uptake into the soil and thus into the plants (Raliya *et al.*, 2016). Therefore, these results suggest

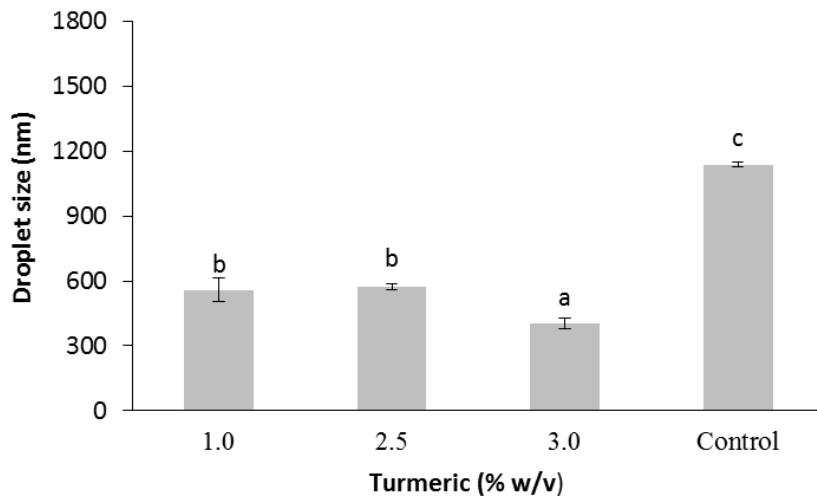


Figure 2. Droplet size for the turmeric fertilizer with 1.0, 2.5 and 3.0 % w/v turmeric. The control was a commercial fertilizer. Different letters in the bars indicate significant differences at $p < 0.5$.

Figura 2. Tamaño de las gotas del fertilizante de cúrcuma con 1,0, 2,5 y 3,0 % p/v de cúrcuma. El control fue un fertilizante comercial. Letras diferentes en las barras indican diferencias significativas a $p < 0,5$.

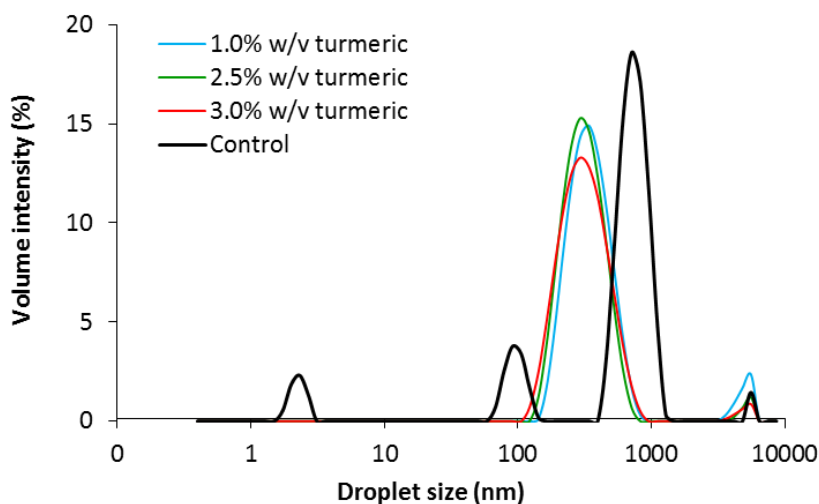


Figure 3. Droplet size distribution for the turmeric fertilizer with 1.0, 2.5 and 3.0 % w/v turmeric. The control was a commercial fertilizer.

Figura 3. Distribución del tamaño de las gotas para el fertilizante de cúrcuma con 1,0, 2,5 y 3,0 % p/v de cúrcuma. El control fue un fertilizante comercial.

that whole milk could be an efficient natural emulsifier with significant potential for agricultural applications, highlighting that a homogeneous droplet size facilitates nutrient availability and uptake.

Soil characterization

Nitrogen, phosphorus, and potassium levels. Nitrogen is needed in the early flowering stage to promote strong growth because it increases protein synthesis (Hardjowigeno, 2003). Phosphorus plays a key role in the early stages of plant development to ensure good root growth and flowering (Hariyadi *et al.*, 2019). Potassium is needed in the metabolic processes of photosynthesis, essential during plant growth (Sutejo, 2002). The absorption of nitrogen, phosphorus and potassium by the tomato plants treated with 1.0, 2.5 and 3.0 % w/v turmeric are presented in Fig. 4. Soil moisture was adjusted to 25.6 ± 2.4 % (wet basis) during the analysis, and soil pH remained constant at 5.8 ± 0.2 .

Fig. 4A showed that, in all cases, there was an early uptake of nitrogen from the soil by the plants, showing significant differences between the control and the plants treated with the different fertilizer formulations. In addition, among the different treatments, there were significant differences in the amount of nitrogen available both at the beginning and the end of the cultivation process. In the beginning, the formulation with 3.0 % w/v turmeric had a greater amount of available nitrogen, while at the end of the cultivation period, the formulation with 2.5 % w/v turmeric had a greater amount of available nitrogen in the soil, which contributed to the better yields and quality of the fruits obtained with this formulation. The turmeric concentrations at 1.0 and 3.0 % w/v showed a lower amount of available nitrogen after the flowering stage. This finding could suggest a higher nitrogen consumption by tomato plants in these treatments. However, the soil with 2.5 % w/v turmeric showed a higher amount of available nitrogen after flowering, which could indicate a lower nitrogen consumption by these tomato plants. On the other hand, the control soil exhibited the lowest nitrogen level, which decreased during the time studied. This finding could confirm that the control soil was low in nitrogen, and probably most of it was utilized by the plant.

Fig. 4B shows that the plants during their early stage of development were able to consume the available phosphorus in the soils treated with 1.0 and 3.0 % w/v turmeric without problems. It is also observed that at the beginning of the process, the sample with 2.5 % w/v turmeric had the highest available phosphorus content in the soil, being significantly different from the rest of the treatments and the control. However, the soil treated with 2.5 % w/v turmeric at the end of the process showed higher phosphorus levels compared to the other two concentrations, suggesting that phosphorus

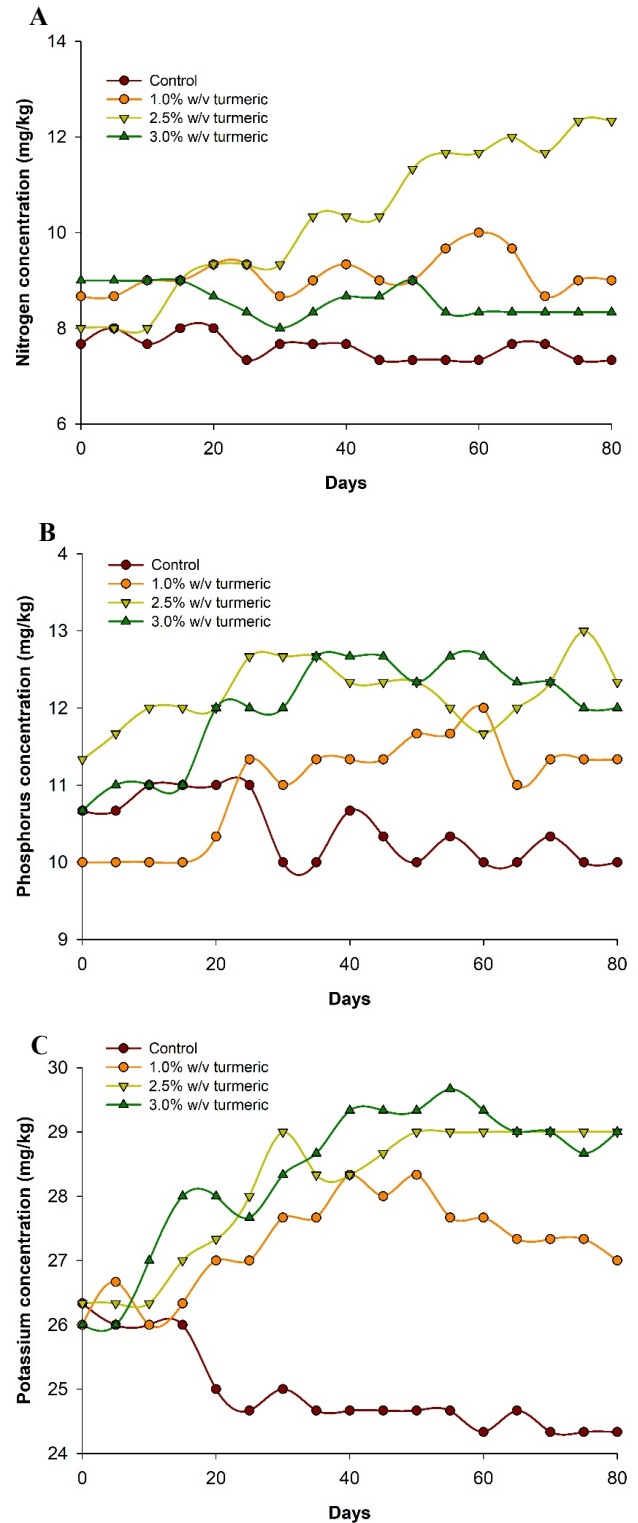


Figure 4. Nitrogen (A), phosphorus (B), and potassium (C) levels in the soil treated with turmeric fertilizer at 1.0, 2.5 and 3.0 % w/v turmeric where tomato plants were cultivated. The control was soil without added fertilizer.

Figura 4. Niveles de nitrógeno (A), fósforo (B) y potasio (C) en el suelo tratado con fertilizante de cúrcuma al 1,0, 2,5 y 3,0 % p/v de cúrcuma en el que se cultivaron plantas de tomate. El control fue un suelo sin adición de fertilizante.

phorus was not available to the plant. The control soil (no fertilizer added) showed phosphorus levels above the level of the soil treated with 1.0 % w/v turmeric at the early plant stage; this finding could be key in suggesting that the soil treated with 1.0 % w/v turmeric showed the highest level of available phosphorus.

Figure 4C shows no significant differences in the available potassium content of the soil at the beginning of the process. In addition, the three turmeric concentrations evaluated exhibited similar trends with respect to potassium levels, however, the soil treated with 1.0 % w/v turmeric showed a decrease in potassium levels after 40 days, which could be associated with higher availability of potassium for the plant in that soil. The behavior of the potassium level in the control soil was remarkable because the significant decrease could indicate that potassium was probably the least available nutrient. Therefore, the soil treated with 1.0 % w/v turmeric offers the most suitable availability of nitrogen, phosphorus and potassium for the flowering and growth of tomato plants and the ripening of their fruits.

Moisture-holding capacity. The water for irrigation is limited in the world, so improving its use efficiency is essential for agriculture (Chicas-Soto et al., 2014). In this regard, moisture-holding capacity is the ability of certain soil textures to physically hold water against the force of gravity. Table 2 shows the effect of turmeric concentration on the moisture-holding capacity of the crop soil; differences between the treatments ranging from 35.41 to 50.65 (g water retained/ 100 g dry soil) were significant ($p < 0.05$). The results showed that soil treated with the TFs had a better moisture-holding capacity, especially the soils treated with 2.5 and 3 % w/v turmeric. It has been shown that organic nutrients in-

Table 2. Moisture-holding capacity in the soil treated with turmeric fertilizer at 1.0, 2.5 and 3.0 % w/v turmeric. The control was a soil without added fertilizer.

Cuadro 2. Capacidad de retención de humedad en el suelo tratado con fertilizante de cúrcuma al 1,0, 2,5 y 3,0 % p/v de cúrcuma. El control fue un suelo sin adición de fertilizante.

Turmeric (% w/v)	MHC $\left(\frac{\text{g water retained}}{100 \text{ g of dry soil}}\right)$
1.0	39.21 ± 1.23 ^b
2.5	44.61 ± 1.75 ^c
3.0	50.65 ± 3.54 ^d
Control	35.41 ± 2.14 ^a

where: MHC is moisture-holding capacity. Different superscript letters indicate significant differences ($p < 0.5$).

fluence soil properties improving water retention due to an increased cation exchange capacity (Kaingo et al., 2018). The main organic nutrients are carbohydrates, proteins, lipids, and vitamins. A tablespoon of turmeric powder has nearly, 6 g of carbohydrates, 2 g of fibre (as polysaccharides), and 1 g of protein (Correa et al., 2020). In consequence, the increased water retention capacity of the soils treated with TF (> 1.0 % w/v turmeric), might be explained by the composition provided by turmeric.

It has been established that soils with greater organic matter content, show positive alterations in their structure that lead to decreased degradation and increased moisture-holding capacity (Meza-Pérez and Geissert-Kientz, 2006), considering that soil organic matter corresponds to organic carbon compounds and soil carbon content is closely related to nitrogen level (Mahal et al., 2019). Therefore, the increase of nitrogen level in the crop soil during the study period (from 8.0 to 12.3 mg/kg) could suggest an increase of organic matter content in the crop soil with the addition of TF. The crop soil without TF addition exhibited a decrease in its nitrogen level during the same period (from 7.7 to 7.3 mg/kg). Therefore, these findings suggest that emulsified turmeric in TF could contribute to the plant water requirement and its organic matter content.

Tomato characterization

Colour values. Colour is one key quality parameter in the tomato. This property is affected by the availability of nutrients and water in the soil (Daza et al., 2009). Table 3 showed the colour changes of tomatoes in numerical terms with the L^* , a^* , and b^* parameters during ripening in plants from the different treatments. The tomato colour parameters for L^* (from white to black), a^* (from green to red), and b^* (from blue to yellow) showed values in the ranges of 37.23–40.96, 21.03–33.25, and 34.31–37.46, respectively. For a ripe tomato, L^* value is usually in the range 40.0–42.7, a^* value in the range of 17.9–29.6, and b^* value in the range of 27.0–29.4 (Castro et al., 2021). Therefore, L^* and a^* parameters coincided with the normal ranges, but b^* parameter was above the normal range.

The lightness of tomatoes from plants grown in soils treated with turmeric at concentrations > 1.0 % w/v decreased, which could be a consequence of the higher carbohydrate contribution of turmeric when the concentration was > 1.0 % w/v, probably due to gelation of the water available that is absorbed by the root and, therefore, resulting in insufficient access of the plant to the soil water (Kaingo et al., 2018). The a^* values of the tomatoes from plants grown in soils treated can be interpreted considering the chlorophyll degradation and the synthesis of lycopene pigments (Barreiro et al., 1997). Thus, a^* values increased as L^*

Table 3. Comparison of colour parameters in tomatoes cultivated in soils treated with turmeric fertilizer at 1.0, 2.5 and 3 % w/v turmeric. The control was a tomato fruit from a plant cultivated in soil without added fertilizer.**Cuadro 3.** Comparación de los parámetros de color en tomates cultivados en suelos tratados con fertilizante de cúrcuma al 1,0, 2,5 y 3 % p/v de cúrcuma. El control fue un fruto de tomate desde una planta cultivada en suelo sin adición de fertilizante.

Turmeric (% w/v)	L^*	a^*	b^*	ΔE^*
1.0	40.96 ± 1.07 ^a	21.03 ± 2,12 ^a	35.02 ± 2.37 ^{ab}	5.23 ± 1.90 ^a
2.5	37.60 ± 1.12 ^b	33.25 ± 1,26 ^b	37.46 ± 1.00 ^b	10.94 ± 3.27 ^b
3.0	37.23 ± 1.66 ^{bcd}	30.72 ± 1,72 ^b	35.04 ± 3.15 ^{ab}	9.04 ± 2.70 ^b
Control	39.05 ± 1.41 ^{abcd}	23.07 ± 2,92 ^a	34.31 ± 1.63 ^a	–

where: L^* is lightness from white to black, a^* is colour parameter from green to red, b^* is colour parameter from blue to yellow, and ΔE^* is total colour difference. Different superscript letters in the same column indicate significant differences ($p < 0.05$).

values decreased when the turmeric concentration was > 1.0 % w/v, which means a darkening of the red colour (tomato totally red). This finding could suggest an enhancement of the tomato ripening rate when the turmeric concentration was > 1.0 % w/v. The reported b^* values could be related to higher levels of xanthophyll pigments (yellow colour), which reach their highest concentration before tomato ripening (López-Camelo and Gómez, 2004). The ΔE^* values ranged from 5.23 to 10.94, suggesting that the colour parameters (L^* , a^* , and b^*) of tomatoes from plants grown in soils treated with TF exhibited marked significant differences compared to the control tomato (from a plant cultivated in soil without added fertilizer) (Zapata *et al.*, 2007). Therefore, the results suggest that plants cultivated in soils treated with turmeric concentrations > 1.0 % w/v, improved the ripening rate of their tomatoes, as well as the content of lycopene and xanthophyll pigments.

Soluble solid content and pH value. The soluble solid content and acidity (or pH value) are two key chemical parameters that influence the ripening and postharvest quality of tomatoes (Huang *et al.*, 2018). Table 4 showed significant differences in the soluble solid content and pH value among the tomatoes from plants cultivated in soils with added TF. The soluble solid content ranged from 4.87 to 6.36 °Brix, which coincides with other reports (Tigist *et al.*, 2013; Huang *et al.*, 2018). It has been reported that soluble solid content in tomatoes increases with colour changes during the ripening (Tadesse *et al.*, 2015), which would be consistent with the results obtained in the present study. The tomatoes cultivated in soils with added TF exhibited pH values ranging from 4.05 to 4.24, being consistent with tomato juices studied (pH from 4.05 to 4.64), and ‘Sun Bright’ tomatoes (pH between 4.0 and 4.3) reported by Astuti *et al.* (2018) and Huang *et al.* (2018), respectively. The increase of pH with turmeric concentrations > 1.0 % w/v

suggests the presence of organic acids at a low content, which could lead to a rapid microbiological deterioration of the harvested tomatoes (Rao and Lakshmanan, 2018). Although other studies report that a normal pH for ripened tomatoes can exceed 4.6, this pH would be the upper limit to qualify the tomatoes as acidic.

In consequence, a pH lower than 4.6 is desirable because the shelf life of tomatoes can be extended (Tigist *et al.*, 2013). In general, studies suggest that the acidity decrease (and thus the pH) during the ripening of tomatoes (Castro *et al.*, 2005). Therefore, the increase in soluble solid content and pH of tomatoes from plants cultivated in soils with turmeric concentrations >1.0 % w/v could mean that tomato plants treated with high turmeric concentration would produce tomato fruits with a higher sugar content and a lower content of free

Table 4. Soluble solid content and pH value in tomatoes cultivated in soils treated with turmeric fertilizer at 1.0, 2.5 and 3.0 % w/v turmeric. The control was a tomato fruit from a plant cultivated in soil without added fertilizer.**Cuadro 4.** Contenido de sólidos solubles y valor de pH en tomates cultivados en suelos tratados con fertilizante de cúrcuma al 1,0, 2,5 y 3,0 % p/v de cúrcuma. El control fue un fruto desde tomate de una planta cultivada en suelo sin adición de fertilizante.

Turmeric (% w/v)	Soluble solid content (° Brix)	pH value
1.0	4.99 ± 0.03 ^a	4.05 ± 0.02 ^a
2.5	6.36 ± 0.11 ^b	4.24 ± 0.04 ^b
3.0	6.07 ± 0.23 ^b	4.21 ± 0.07 ^b
Control	4.87 ± 0.12 ^a	4.17 ± 0.03 ^b

Different superscript letters in the same column indicate significant differences ($p < 0.05$).

organic acids, which is a disadvantage because it could cause a higher incidence of fungal infection.

Diameter and tomato number. The tomato growth (expressed as its diameter) and number of tomatoes per plant were measured to evaluate the effect of turmeric concentration. Table 5 showed that the used TF significantly ($p < 0.05$) increased the diameter and tomato number compared with the results recorded from the control tomato (from a plant cultivated in soil without added fertilizer). The results were consistent with the high photosynthetic rate observed in tomato plants (see Table 6). These findings partially coincided with the results found by Tahamolkonan *et al.* (2022) obtained after the organic fertilization of tomato plants. Therefore, the TF exhibited positive effects on tomato growth and yield.

Photosynthetic index

Table 6 showed the effect of turmeric concentration (1.0, 2.5 and 3 % w/v) on the photosynthetic index in the tomato plant leaves. The photosynthetic index in these plants was significantly higher ($p < 0.05$) than in the control (tomato plant leaves cultivated in soil without added fertilizer) and increased significantly ($p < 0.05$) as the turmeric concentration increased (> 1.0 % w/v). Schwarz *et al.* (2002) attributed the improvement of tomato quality to the addition of macronutrients in the soil. In addition, an increase of nutrients in the soil could also affect photosynthesis and, as result, the tomato plant growth and its yield (Kohzuma and Hikosaka, 2018), which was verified with a high

Table 5. Diameter and tomato number in tomatoes cultivated in soils treated with turmeric fertilizer at 1.0, 2.5 and 3.0 % w/v turmeric. The control was a tomato fruit from a plant cultivated in soil without added fertilizer.

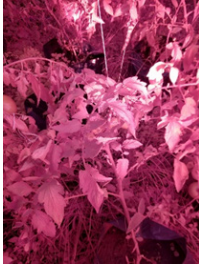


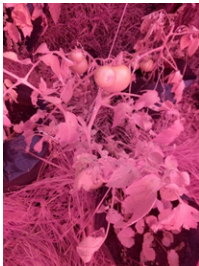
Cuadro 5. Diámetro y número de tomates cultivados en suelos tratados con fertilizante de cúrcuma al 1,0, 2,5 y 3,0 % p/v de cúrcuma. El control fue un fruto de tomate desde una planta cultivada en suelo sin adición de fertilizante.

Turmeric (% w/v)	Tomato plants	
	Diameter (mm)	Tomato number
1.0	35.42 ± 2.50 ^a	10 ± 2 ^b
2.5	43.08 ± 3.92 ^b	15 ± 1 ^c
3.0	52.42 ± 5.02 ^c	16 ± 2 ^c
Control	33.70 ± 1.96 ^a	8 ± 1 ^a

Different superscript letters in the same column indicate significant differences ($p < 0.05$).

Table 6. Photosynthetic index in leaves of tomato plant cultivated in soils treated with turmeric fertilizer at 1.0, 2.5 and 3.0 % w/v turmeric. The control consisted of leaves of tomato plants cultivated in soil without fertilizer added.

Cuadro 6. Índice fotosintético en hojas de plantas de tomate cultivadas en suelos tratados con fertilizante de cúrcuma al 1,0, 2,5 y 3,0 % p/v de cúrcuma. El control consistió en hojas de planta de tomate cultivadas en suelo sin adición de fertilizante.

Turmeric (% w/v)		Photosynthetic index
1.0		0.58 ± 0.02 ^a
2.5		0.65 ± 0.06 ^b
3.0		0.72 ± 0.04 ^c
Control		0.52 ± 0.01 ^a

Different superscript letters indicate significant differences ($p < 0.5$).

her number of tomatoes compared with the control (to see Table 5). Therefore, a higher contribution of macronutrients (such as carbohydrates, fiber, and proteins) in the TF when the turmeric concentration was > 1.0 % w/v, could explain the high levels of photosynthetic responses obtained in the study.

CONCLUSION

Turmeric, coffee beans, banana peels and wood ashes were used in the present research for the development of a turmeric fertilizer (TF); this fertilizer improved the tomato size (diameter); the quality of its fruits (colour, soluble solid content and pH value), and plant yield (tomato number). The tomato plants cultivated in the soil fertilized with TF were able to improve their metabolic process, increasing their photosynthetic response with increasing turmeric concentration. The TF allowed to regulate the nitrogen, phosphorus and potassium levels in the crop soil and improved its moisture-holding capacity. Increasing turmeric concentration from 2.5 to 3.0% w/v, produced a more viscous and stable fertilizer.

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DECLARATION OF CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

REFERENCES

- Álvarez-Hernández, J.C., Venegas-Flores, S., Soto-Ayala, C., Chávez-Vargas, A., Zavala-Sánchez, L., 2011. Uso de fertilizantes químicos y orgánicos en cebolla (*Allium cepa* L.) en Apatzingán, Michoacán, México. *Avances en Investigación Agropecuaria* 15, 29–43.
- Antoniadis, V., Shaheen, S.M., Boersch, J., Frohne, T., Du Laing, G., Rinklebe, J., 2017. Bioavailability and risk assessment of potentially toxic elements in garden edible vegetables and soils around a highly contaminated former mining area in Germany. *Journal of Environmental Management* 186, 192–200. <https://doi.org/10.1016/j.jenvman.2016.04.036>
- Association of Official Analytical Chemist AOAC, 2019. Official methods of analysis (21st ed.), AOAC International, New York, USA.
- Association of Official Analytical Chemists AOAC, 2012. Metals in Food, MIN-302/META. Standard Methods for the Examination of Water and Wastewater (22nd ed.), AOAC International, New York, USA.
- Astuti, D.S., Salengke, S., Laga, A., Mariyati Bilangd, M., Mochtar, H., Warisf, A., 2018. Characteristics of pH, total acid, total soluble solid on tomato juice by ohmic heating technology. *International Journal of Sciences: Basic and Applied Research* 39, 21–28.
- Ayusto-Yuste, M.C., González-Cebrino, F., Lozano-Ruiz, M., Fernández-León, A.M., Bernalte-García, M.J., 2022. Influence of ripening stage on quality parameters of five traditional tomato varieties grown under organic conditions. *Horticulturae* 8, 313. <https://doi.org/10.3390/horticulturae8040313>
- Barreiro, J.A., Milano, M., Sandoval, A.J., 1997. Kinetics of colour change of double concentrated tomato paste during thermal treatment. *Journal of Food Engineering* 33, 359–371. [https://doi.org/10.1016/S0260-8774\(97\)00035-6](https://doi.org/10.1016/S0260-8774(97)00035-6)
- Bejar Pulido, S.J., Cantú Silva, I., Yáñez Díaz, M.I., Luna Robles, E.O., 2020. Moisture retention curves and pedotransfer models in Andosol under different land uses. *Revista Mexicana de Ciencias Forestales* 11, 31–50. <https://doi.org/10.29298/rmcf.v11i59.666>
- Bergstrand, K. J., 2022. Organic fertilizers in greenhouse production systems—a review. *Scientia Horticulturae* 295, 110855. <https://doi.org/10.1016/j.scienta.2021.110855>
- Cano, M.A., 2011. Interacción de microorganismos benéficos en plantas: Micorrizas, *Trichoderma spp.* y *Pseudomonas spp.* Una revisión. *Revista U.D.C.A. Actualidad & Divulgación Científica* 14, 15-31.
- Castro, L.R., Vigneault, C., Charles, M.T., Cortez, L.A.B., 2005. Effect of cooling delay and cold-chain breakage on 'Santa Clara' tomato. *Journal of Food Agriculture and Environment* 3, 49–54.
- Castro, T.A., Leite, B.S., Assunção, L.S., de Jesus Freitas, T., Colauto, N.B., Linde, G.A., Otero, D.M., Machado, B.A.S., Ferrreira Ribeiro, C.D., 2021. Red tomato products as an alternative to reduce synthetic dyes in the food industry: A review. *Molecules* 26, 7125. <https://doi.org/10.3390/molecules26237125>
- Chicas Soto, R.A., Vanegas Chacón, E.A., García Álvarez, N., 2014. Determinación indirecta de la capacidad de retención de humedad en suelos de la subcuenca del río Torjá, Chiquimula, Guatemala. *Revista Ciencias Técnicas Agropecuarias* 23, 41–46.
- Correa, D.P.N., Osorio, J.R., Zúñiga, O., Andica, R.A.S., 2020. Determinación del valor nutricional de la harina de cúrcuma y la actividad antioxidante de extractos del rizoma de *Cúrcuma longa* procedente de cultivos agroecológicos y convencionales del Valle del Cauca-Colombia. *Revista Colombiana de Química* 49, 26. <https://doi.org/10.15446/rev.colomb.quim.v1n49.79334>
- Dahlawi, S.M., Nazir, W., Iqbal, R., Asghar, W., Khalid, N., 2020. Formulation and characterization of oil-in-water nanoemulsions stabilized by crude saponins isolated from onion skin waste. *Royal Society of Chemistry Advances* 10, 39700–39707. <https://doi.org/10.1039/D0RA07756A>
- Daza, C., Gutiérrez, J.M., González, J.A., Esteban, A., Gil, C., Grajera, J., 2009. Influencia de la dosis de riego en el color y otros parámetros de calidad del tomate de industria. *Actas de Horticultura* 54, 577–581.
- El-Naggar, A., Lee, S.S., Rinklebe, J., Farooq, M., Song, H., Sarimah, A.K., Zimmerman, A.R., Ahmad, M., Shaheen, S.M.,

- Ok, Y.S., 2019. Biochar application to low fertility soils: A review of current status, and future prospects. *Geoderma* 337, 536–554. <https://doi.org/10.1016/j.geoderma.2018.09.034>
- FAO, 2011. The state of the world's land and water resources for food and agriculture (SOLAW) – Managing systems at risk. Food and Agriculture Organization of the United Nations, Rome and Earthscan, London.
- Hardjowigeno, S., 2003. Soil classification and pedogenesis. Akademika Pressindo, Jakarta, Pages: 354.
- Hariyadi, B.W., Nizak, F., Nurmalasari, I.R., Kogoya, Y., 2019. Effect of dose and time of NPK fertilizer application on the growth and yield of tomato plants (*Lycopersicon esculentum* Mill). *Agricultural Science* 2, 101–111.
- Hong, T., Iwashita, K., Shiraki, K., 2018. Viscosity control of protein solution by small solutes: A review. *Current Protein and Peptide Science* 19, 746–758. <https://doi.org/10.2174/1389203719666171213114919>
- Huang, Y., Lu, R., Chen, K., 2018. Assessment of tomato soluble solids content and pH by spatially-resolved and conventional Vis/NIR spectroscopy. *Journal of Food Engineering* 236, 19–28. <https://doi.org/10.1016/j.jfoodeng.2018.05.008>
- Ilyin, S.O., Kulichikhin, V.G., Malkin, A.Y., 2015. Rheological properties of emulsions formed by polymer solutions and modified by nanoparticles. *Colloid and Polymer Science* 293, 1647–1654. <https://doi.org/10.1007/s00396-015-3543-6>
- Kai, T., Adhikari, D., 2021. Effect of organic and chemical fertilizer application on apple nutrient content and orchard soil condition. *Agriculture* 11, 340. <https://doi.org/10.3390/agriculture11040340>
- Kai, T., Kubo, M., 2020. Chemical and biological properties of apple orchard soils under natural, organic, hybrid, and conventional farming methods. *Journal of Agricultural Chemistry and Environment* 9, 134–146. <https://doi.org/10.4236/jacen.2020.93012>
- Kai, T., Tamaki, M., 2020. Effect of organic and chemical fertilizer application on growth, yield, and soil biochemical properties of Landrace *Brassica napus* L. leaf-and-stem vegetable and Landrace (Norabona). *Journal of Agricultural Chemistry and Environment* 9, 314–330. <https://doi.org/10.4236/jacen.2020.94023>
- Kai, T., Nishimori, S., Tamaki, M., 2020. Effect of organic and chemical fertilizer application on growth, yield, and quality of small-sized tomatoes. *Journal of Agricultural Chemistry and Environment* 9, 121–133. <https://doi.org/10.4236/jacen.2020.93011>
- Kaingo, J., Tumbo, S.D., Kihupi, N.I., Mbilinyi, B.P., 2018. Prediction of soil moisture-holding capacity with support vector machines in dry subhumid tropics. *Applied and Environmental Soil Science* 2018. <https://doi.org/10.1155/2018/9263296>
- Kohzuma, K., Hikosaka, K., 2018. Physiological validation of photochemical reflectance index (PRI) as a photosynthetic parameter using *Arabidopsis thaliana* mutants. *Biochemical and Biophysical Research Communications* 498, 52–57. <https://doi.org/10.1016/j.bbrc.2018.02.192>
- Kovačević, J., Mazur, M., Lalić, A., Josipović, M., Josipović, A., Marković, M., Antunović, J., Vera, C., 2015. Photosynthetic performance index in early stage of growth, water use efficiency, and grain yield of winter barley cultivars. *Chilean Journal of Agricultural Research* 75, 275–283. <http://dx.doi.org/10.4067/S0718-58392015000400002>
- Kulkarni, Y., Warhade, K.K., Bahekar, S., 2014. Primary nutrients determination in the soil using UV spectroscopy. *International Journal of Emerging Engineering Research and Technology* 2, 198–204.
- Kyomuhendo, P., Tenywa, M.M., Semalulu, O., Lenssen, A., Yost, R., Mazur, R., Kyebogola, S., 2020. Lime requirements for bean production on two contrasting soils of Lake Victoria Crescent agro-ecological zone. *African Journal of Agricultural Research* 15, 531–537. <https://doi.org/10.5897/AJAR2019.14455>
- Leiva-Vega, J., Villalobos-Carvajal, R., Ferrari, G., Donsì, F., Zúñiga, R.N., Shene, C., Beldarraín-Iznaga, T., 2020. Influence of interfacial structure on physical stability and antioxidant activity of curcumin multilayer emulsions. *Food and Bioproducts Processing* 121, 65–75. <https://doi.org/10.1016/j.fbp.2020.01.010>
- Longhurst, B., Nicholson, B., 2010. Rapid on farm estimating NPK content of effluents for land applications. High TechEnviro Solution.
- López-Camelo, A.F., Gómez, P.A., 2004. Comparison of color indexes for tomato ripening. *Horticultura Brasileira* 22, 534–537. <https://doi.org/10.1590/S0102-05362004000300006>
- Ma, P., Zeng, Q., Tai, K., He, X., Yao, Y., Hong, X., Yuan, F., 2017. Preparation of curcumin-loaded emulsion using high pressure homogenization: Impact of oil phase and concentration on physicochemical stability. *LWT - Food Science and Technology* 84, 34–46. <https://doi.org/10.1016/j.lwt.2017.04.074>
- Mahal, N.K., Osterholz, W.R., Miguez, F.E., Poffenbarger, H.J., Sawyer, J.E., Olk, D.C., Archontoulis, S.V., Castellano, M.J., 2019. Nitrogen fertilizer suppresses mineralization of soil organic matter in maize agroecosystems. *Frontiers in Ecology and Evolution* 7, 59. <https://doi.org/10.3389/fevo.2019.00059>
- McClements, D.J., 2016. Food emulsions: Principles, practices, and techniques. Third edition. Boca Raton, FL: CRC Press. <https://doi.org/10.1201/9781420039436>
- Meza-Pérez, E., Geissert-Kientz, D., 2006. Estabilidad de estructura en andisoles de uso forestal y cultivados. *Terra Latinoamericana* 24, 163–170.
- Mezger, T., 2002. The Rheology-Handbook — For users of rotational and oscillatory rheometers. Hanover, Vincentz Verlag. 252 pp.
- Mikkelsen, R.L., Behel, A.D., Williams, H.M., 1993. Addition of gel-forming hydrophilic polymers to nitrogen fertilizer solutions. *Fertilizer Research* 36, 55–61. <https://doi.org/10.1007/BF00749948>
- National Institute of Standardization, 2002. Official methods of analysis. Total Nitrogen, NCh 2748. Chile.
- Raliya, R., Franke, C., Chavalmane, S., Nair, R., Reed, N., Biswas, P., 2016. Quantitative understanding of nanoparticle uptake in watermelon plants. *Frontiers in Plant Science* 7, p.1288. <https://doi.org/10.3389/fpls.2016.01288>
- Ramírez-Gil, J.G., Castañeda Sánchez, D.A., Morales Osorio, J.G., 2013. Dinámica microbiana del suelo asociada a diferentes estrategias de manejo de *Phytophthora cinnamomi*.

- mom* Rands en aguacate. *Revista Ceres* 60, 811–819. <https://doi.org/10.1590/S0034-737X2013000600009>
- Rao, M.R.K., Lakshmanan, V., 2018. Study of bio-preservative potential of turmeric on tomato. *Indo American Journal of Pharmaceutical Sciences* 5, 3818–3829. <https://doi.org/10.5281/zenodo.1248148>
- Reganold, J.P., Glover, J.D., Andrews, P.K., Hinman, H.R., 2001. Sustainability of three apple production systems. *Nature* 410, 926–930. <https://doi.org/10.1038/35073574>
- Salamat, S.S., Hassan, M.A., Shirai, Y., Hanif, A.H.M., Norizan, M.S., Zainudin, M.H.M., Mustapha, N.A., Isa, M.N.M., Bakar, M.F.A., 2021. Effect of inorganic fertilizer application on soil microbial diversity in an oil palm plantation. *Bio Resources* 16, 2279–2302. <https://doi.org/10.15376/biores.16.2.2279-2302>
- Schwarz, D., Kläring, H.P., Van Iersel, M.W., Ingram, K.T., 2002. Growth and photosynthetic response of tomato to nutrient solution concentration at two light levels. *Journal of the American Society for Horticultural Science* 127, 984–990. <https://doi.org/10.21273/JASHS.127.6.984>
- Shaheen, N., Rahim, A.T.M.A., Mohiduzzaman, M., Bari, M.L., Rahman, S.M.M., 2013. Development of a food composition table for Bangladesh. [2015-12-25]. <http://www.nfpensp.org/agridrupal/sites/default/files/ToR-Project-Final-Report.pdf>
- Sheng, B., Li, L., Zhang, X., Jiao, W., Zhao, D., Wang, X., Wan, L., Li, B., Rong, H., 2018. Physicochemical properties and chemical stability of β -carotene bilayer emulsion coated with bovine serum albumin and Arabic gum compared to monolayer emulsions. *Molecules* (Basel, Switzerland) 23, 495. <https://doi.org/10.3390/molecules23020495>
- Simon, S., Theiler, S., Knudsen, A., Øye, G., Sjöblom, J., 2010. Rheological properties of particle-stabilized emulsions. *Journal of Dispersion Science and Technology* 31, 632–640. <https://doi.org/10.1080/01932690903218062>
- Spricigo, P.C., Freitas, T.P., Purgatto, E., Ferreira, M.D., Correa, D.S., Bai, J., Brecht, J.K., 2021. Visually imperceptible mechanical damage of harvested tomatoes changes ethylene production, color, enzyme activity, and volatile compounds profile. *Postharvest Biology and Technology* 176, 111503. <https://doi.org/10.1016/j.postharvbio.2021.111503>
- Sutejo, M.M., 2002. Pupuk dan Cara Pemupukan. Jakarta: Rineka Cipta.
- Tadesse, T.N., Ibrahim, A.M., Abteu, W.G., 2015. Degradation and formation of fruit color in tomato (*Solanum lycopersicum* L.) in response to storage temperature. *American Journal of Food Technology* 10, 147–157. <https://doi.org/10.3923/ajft.2015.147.157>
- Tahamolkonan, M., Ghahsareh, A.M., Ashtari, M.K., Honarjoo, N., 2022. Tomato (*Solanum lycopersicum*) growth and fruit quality affected by organic fertilization and ozonated water. *Protoplasma* 259, 291–299. <https://doi.org/10.1007/s00709-021-01657-7>
- Tigist, M., Workneh, T.S., Woldetsadik, K., 2013. Effects of variety on the quality of tomato stored under ambient conditions. *Journal of Food Science and Technology* 50, 477–486. <https://doi.org/10.1007/s13197-011-0378-0>
- Upendra, R.S., Pratima, K., Manjunatha Reddy, A.H., 2011. Turmeric powder (*Curcuma longa* Linn.) as an antifungal agent in plant tissue culture studies. *International Journal of Engineering Science and Technology* 3, 7899–7904.
- Zapata, L., Gerard, L., Davies, C., Oliva, L., Schvab, M., 2007. Correlación matemática de índices de color del tomate con parámetros texturales y concentración de carotenoides. *Ciencia, Docencia y Tecnología* 18, 207–226.
- Zhu, Y., Gao, H., Liu, W., Zou, L., McClements, D.J., 2020. A review of the rheological properties of dilute and concentrated food emulsions. *Journal of Texture Studies* 51, 45–55. <https://doi.org/10.1111/jtxs.12444>

