Scientific Papers. Series B, Horticulture. Vol. LXVIII, No. 2, 2024
Print ISSN 2285-5653, CD-ROM ISSN 2285-5661, Online ISSN 2286-1580, ISSN-L 2285-5653

ENHANCING *PHYSALIS IXOCARPA* L. CROP YIELD QUANTITY AND QUALITY USING BIOCHAR, WOOD VINEGAR AND CROPMAX: A SUSTAINABLE APPROACH

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Abstract

Physalis ixocarpa L., commonly known as tomatillo or Mexican husk tomato, is an economically valuable crop due to its nutritional value and culinary versatility. However, its growth and yield can be affected by various factors including soil quality, nutrient availability, and environmental stressors. In this study, we investigated the effects of employing biochar, wood vinegar, and CropMax—a proprietary organic fertilizer—on the growth, yield, and some quality parameters of Physalis ixocarpa L. Results demonstrated that the combined application of biochar, wood vinegar, and CropMax significantly improved the growth characteristics of Physalis ixocarpa L. The treatments applied positively influenced both quantitative and qualitative yield parameters compared to control variant. This study highlights the potential of employing biochar, wood vinegar, and CropMax as a sustainable approach to enhance the growth, yield, and soil health of Physalis ixocarpa. The findings underscore the importance of integrated management strategies for sustainable agriculture practices, emphasizing the potential for improving crop productivity while maintaining soil health and fertility

Key words*: tomatillo, pyrolized biomass, pyroligneous acid, eco-friendly produces, crop enhancer.*

INTRODUCTION

The imperative of addressing the exponential growth of the global population necessitates the establishment of sustainable and productive agroecosystems to meet current food demands while preserving crucial natural resources for future generations (Francis & Porter, 2011). An indispensable element in achieving sustainability lies in the conservation of biodiversity at the plant species level, with a specific emphasis on those less cultivated yet possessing significant potential (van Zonneveld et al., 2023).

Within this context, *Physalis ixocarpa* Brot., commonly known as "tomate verzi" (green tomato), "tomate de Cáscara" (husk tomato), or "tomatillo" (Svobodova & Kuban, 2018), emerges as an enigmatic gem in the horticultural domain. Belonging to the Solanaceae family, tomatillo is revered for its succulent and tangy green fruits enclosed in papery husks, primarily consumed fresh in Mexico, where the *Physalis* genus boasts over 70 species, mostly endemic (Mazova et al., 2020), the United States, and Central America (Mulato-Brito & Peña-Lomelí, 2007). The fruit develops within a protective calyx, offering defense against adverse climate conditions, diseases, insects, and environmental factors (Lim, 2013). Originating from Mesoamerica, this perennial plant has transcended its historical confines, evolving into a versatile and sought-after crop with diverse culinary applications. The distinctive flavor profile and ornamental allure of tomatillos have spurred increased interest in their cultivation, both in traditional open fields and sophisticated glasshouse environments.

Tomatillos hold global culinary significance, particularly in Mexican cuisine, where their zesty and citrusy notes enhance the flavors of salsas, sauces, and traditional dishes. Beyond their gustatory appeal, tomatillo plants, with their sprawling growth habit and verdant foliage, contribute aesthetic dynamism to agricultural landscapes and controlled environments.

From a medicinal perspective, tomatillos contain a substantial amount of phytochemicals, including polyphenols, recognized for their antioxidant properties (Silva et al., 2016), and have garnered attention for potential hypoglycemic effects (Gulati et al., 2012). Furthermore, tomatillos are acknowledged for their antibacterial, antitumor, immunomodulatory, and antipyretic actions (Guerrero-

Romero et al., 2021), traditionally employed in alternative treatments for various conditions, including liver disorders, asthma, malaria, and dermatitis (Zhang & Tong, 2016).
Moving to the challenges of commercial greenhouse cultivation of husk tomatoes, constraints include the necessity for appropriately designed greenhouses meeting plant specifications and a satisfactory availability of varieties suited to this cultivation system (Santiaguillo et al., 2009; Ponce et al., 2012).
Furthermore, achieving soil sustainability mandates the adoption of practices aimed at minimizing the inputs of synthetic chemical fertilizers. In recent years, biochar and wood vinegar have emerged as prominent alternative sources of inputs intended to enhance soil fertility.
Biochar, produced through the pyrolysis of waste biomass in controlled oxygen conditions (Lehmann, 2007), exhibits promise as a soil amendment. It improves soil physico-chemical properties, fosters plant growth, and mitigates soil pollution (Zheng et al., 2013). Although studies suggest that biochar can increase soil organic carbon and water holding capacity, benefiting plant growth (Jeffery et al., 2011), its impact on yield is not consistently positive; for instance, it may enhance nutrient availability without consistently improving crop yields (Vaccari et al., 2015). Wood vinegar, a by-product of biomass pyrolysis, has also been reported to enhance crop yields and nutrient uptake when applied to agricultural soils (Rui et al., 2014).

MATERIALS AND METHODS

The research has been carried out in 2023, into an unheated glasshouse within Vegetable Research and Development Station Bacău conventional agriculture plot, characterized by a well-developed alluvial soil with a loam-sandy composition, a pH level ranging from 6.2 to 6.8, and an organic matter content between 2% and 2.6%. The prior year's preceding crop was `Auria Bacaului` climbing bean. Tomatillo seedlings were grown in a controlled greenhouse environment using nutrient cubes and alveolar trays, with the initial sowing on March 14th and subsequent transplantation to the field on May 19th. The planting scheme included two distinct rows, with 70 cm between rows and 35 cm between plants/row, respectively. The tomatillo plants were not subjected to pruning throughout the vegetative season, instead being espaliered in accordance with the number of branches. Disease and pest management relied exclusively on copper-based products (two applications of Boille Bordellaise - 0.5% were conducted during the vegetation season). Irrigation was carried out using drip irrigation tape from May until the first ten days of September.

Experimental arrangement

The randomized experimental setup comprised four variants and three repetitions (10 plants per repetition), arranged in a pair of rows, as illustrated in Table 1.

Table 1. Randomized experimental setup

No.	Experimental variants	Applied doses	Main product description
V1	1 Biochar application * 2 Cropmax treatments	Biochar - consistent spreading at ground level, succeeded by shallow integration into the soil. Cropmax application - a quantity of 10 ml per 10 liters of water per 100 square meters.	Bio-GEKKA S (Expoclom GK SRL) - pyrolysis carbonization of biomass; compactness < 3 mm - 276 kg/m^3, specific surface area (BET) - 557.76 m^2/g, residue content (550 degrees) - 4.1% (w/w); carbon content (C) - 91.3% (w/w); overall nitrogen (N) - 0.66% (w/w); potassium (K) - 0.25% (w/w); sodium (Na) - 0.02% (w/w); calcium (Ca) - 1.1% (w/w); iron (Fe) - 0.09% (w/w); magnesium (Mg) - 0.05% (w/w); manganese (Mn) - 0.04% (w/w); sulfur (S) - 0.03% (w/w); water-holding capacity - 162.5%; dampness - 6%; acidity level - 8.76 CaCl2, EPA-PAH (devoid of LOQ) - 6 mg/kg.
V2	2 Wood vinegar * 2 Cropmax treatments	Wood vinegar application - an amount of 20 ml per 10 liters of water per 100 square meters. Cropmax application - a quantity of 10 ml per 10 liters of water per 100 square meters.	Bio-GEKKA L (Expoclom GK SRL); it is a byproduct of biomass carbonization through pyrolysis, containing acetic acid and pyroligneous acid; carbon content (C) - 14 g/l; Kjeldahl nitrogen - 3.37 mg/dm^3; potassium (K) - <20 mg/dm^3; boron (B) - <2 mg/dm^3; copper (Cu) - <0.4 mg/dm^3; iron (Fe) - 533 mg/dm^3; phosphorus (P) - <0.4 mg/dm^3; magnesium (Mg) - 0.809 mg/dm^3; manganese (Mn) - 3.42 mg/dm^3; acidity level - 4.24; nitrites (NO2-) <5 mg/dm^3; nitrates (NO3-) <5 mg/dm^3.
V3	2 Cropmax treatments	Cropmax treatment - an application rate of 10 ml per 10 liters of water per 100 square meters.	Cropmax is a highly concentrated foliar fertilizer; pH level - 7, nitrogen (N2) content at 0.2%, phosphorus pentoxide (P2O5) at 0.4%, potassium oxide (K2O) at 0.02%, iron (Fe) concentration of 220 mg/L, magnesium (Mg) content of 550 mg/L, and calcium (Ca) at 10 mg/L.
V4	Control (untreated)		

Quantitative Measurements

Various biometric characteristics, such as plant height, leaf count, stem diameter, no of branches, flower quantity and fruit count, fruit length, width and weight, were determined at plant physiological maturity (Figure 1).

Figure 1. Tomatillo plant during the growing season

Both chlorophyll pigments and anthocyanins were gauged using similar instruments, namely the CCM 200 plus and ACM 200 plus, manufactured by Optisciences. The results were quantified using indices that accurately reflect the overall concentration of chlorophyll pigments and anthocyanins, specifically the Chlorophyll Concentration Index and the Anthocyanin Content Index during a consecutive two-month period (June and July). The findings were displayed dynamically.

The yields obtained for the four different variations were recorded per plant, emphasizing the distinctions among them (Figure 2).

Figure 2. The yield of tomatillo fruits per plant

Quality Measurements

The quality assessment of tomatillo yield under the influence of the three examined treatments included the examination of several factors, including total dry matter (DM), total soluble solids (TSS), and titratable acidity (TA) (Figure 3).

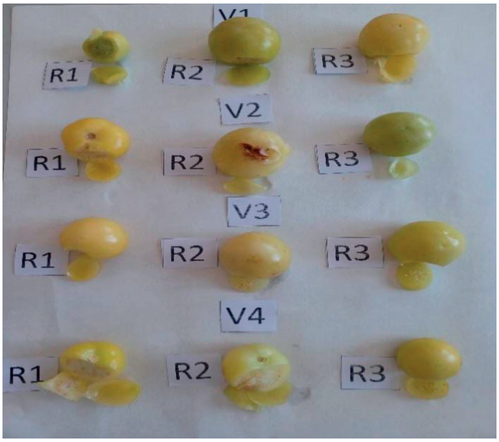

Figure 3. Preparing samples for qualitative determinations

Dry matter content (DM) - Fresh and uniform samples underwent drying in a forced air oven (Biobase) at a controlled temperature of 103 ± 2°C for 24 hours, adhering to AOAC (2000) guidelines. The results are expressed as a percentage.

Total soluble solids (TSS) were measured with a highly accurate handheld refractometer, and the outcomes are reported in degrees Brix, following the methodology described in AOAC (2005) section 932:12 (Figure 4).

Figure 4. Quantification of the total soluble solids content in tomatillo fruit

Titratable acidity (TA) - The percentage of malic acid was calculated using the formula: % malic acid = mL of NaOH x F x 25 x 2 x 0.0067. The results were reported as mean values, along with their respective standard errors. To assess the statistical significance of the total yield achieved per plant across the four different variants, an analysis was conducted using the ANOVA test.

RESULTS AND DISCUSSIONS

The results and analysis presented herein provide a comprehensive examination of key parameters influencing the growth, development, and quality of the tomatillo plants cultivated under various treatment conditions. The investigated parameters encompass a spectrum of key elements acting as indicators of plant growth, physiological status, and fruit quality, offering valuable insights into the efficacy of applied treatments. The multidimensional nature of the analysis allows for a holistic understanding of the effects of these treatments. The combination of Biochar application and Cropmax treatments in V1 leads to the tallest plants (83.22 cm) compared to other treatments (Figure 5). Biochar is known for improving soil fertility and water retention, which could contribute to enhanced plant growth (Jones et al., 2012; Schulz et al., 2013; Rawat et al., 2019; Dai et al., 2020). The positive correlation between Biochar application and increased plant height suggests a potential beneficial effect. V2, involving Wood vinegar and Cropmax treatments, results in plants with a moderate height (76.67 cm) and a relatively high flower count (16.67). Wood vinegar is often considered a natural plant growth promoter (Rogelio, 2018; Zhu et al., 2021; Yavaş et al., 2023). The correlation between Wood vinegar treatment and higher flower count hints at its potential role in influencing reproductive development. V3 involves Cropmax treatments without additional amendments, resulting in plants with a moderate height (72.89 cm) and a lower flower count (12.67). The control variant (V4) has the shortest plants (68.00 cm) but surprisingly exhibits the highest leaf count per branch (52.22) and a comparable flower count (16.11). This may indicate that untreated conditions lead to increased foliage development, possibly compensating for the shorter stature.

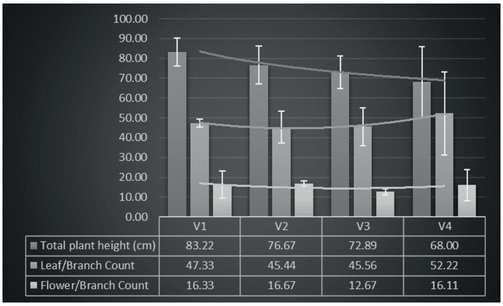

Figure 5. Some parameters of tomatillo plant growth and development influenced by the nutrient blend

Examining stem base diameter provides insights into the structural development of the plants. The relatively large stem base diameter in V1 suggests that the combination of Biochar application and Cropmax treatments contributes to robust structural development (Figure 6). This may be indicative of increased nutrient absorption and enhanced root growth. The high number of branches in V1 correlates with the large stem base diameter, indicating a positive relationship between structural development and branching patterns. This suggests that the treatments applied to V1 not only promote overall plant growth, but also influence branching architecture.

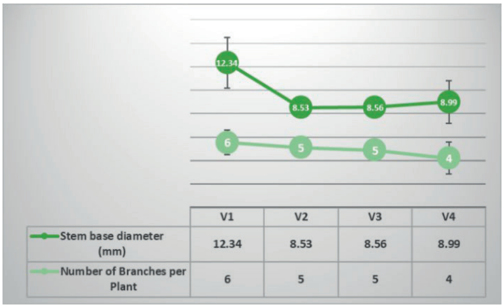

Figure 6. Tomatillo plant stem base diameter and number of branches per plant influenced by the nutrient blend

V2 exhibits a smaller stem base diameter compared to V1, suggesting that the inclusion of Wood vinegar in combination with Cropmax treatments may have a different impact on structural development. The moderate number of branches in V2 correlates with its stem base diameter, indicating a balanced structural development. V3 shows a similar stem base diameter to V2. This suggests that Cropmax treatments are influential in determining the structural development of the plant. Likewise, the consistent number of branches in V3, similar to V2, reinforces the notion that Cropmax treatments play a pivotal role in influencing branching patterns, irrespective of additional amendments.

The control variant (V4) elucidates that untreated tomatillo plants possess the capacity to attain a stem base diameter commensurate with treated counterparts. By contrast, the modest number of branches per plant underscores the consequential impact of fertilization interventions on the intricacies of branching architectures, accentuating the substantial influence treatments exert over the overarching structural development of plants.

The dynamic changes in Chlorophyll Content Index (CCI) and Anthocyanin Content Index (ACI) across the variants provide insights into the plant's physiological responses to different treatments (Figure 7).

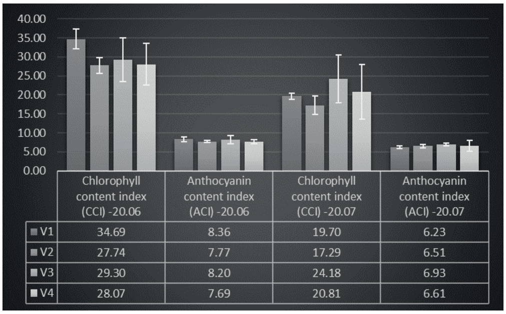

Figure 7. Dynamics of chlorophyll and anthocyanin content of tomatillo leaves during the growing season

Across all variants, the observed dynamics suggest changes in chlorophyll and anthocyanin content over time, indicating potential responses to applied treatments or inherent plant developmental processes. Thus, the decreasing trend over the observed period could be attributed to alterations in plant pigmentation due to various factors, such as applied treatments influence, plant growth stages or environmental conditions.

The number of fruits per plant serves as a critical metric for overall productivity, and its correlation with other parameters provides insights into the holistic impact of applied treatments (Figure 8). Fruit length, width, and average fruit weight collectively contribute to the assessment of fruit quality, with each variant exhibiting unique characteristics influenced by the applied treatments.

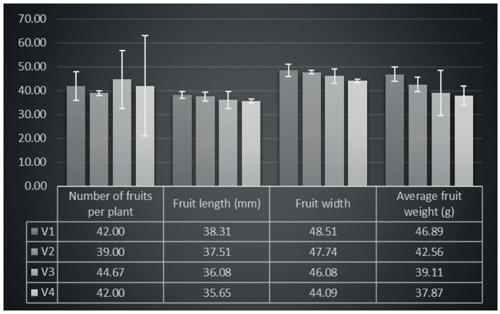

Figure 8. The number of fruits per plant and other morphological characteristics of tomatillo fruits

Among the variants, V3 exhibits the highest number of fruits per plant at 44.67. This suggests that the application of Cropmax treatments alone has a pronounced positive impact on fruit yield. The robust yield in V3 may be attributed to enhanced nutrient availability, potentially promoting fruit set and development.

V1 showcases the longest fruit length at 38.31 mm, emphasizing the positive influence of Biochar application and Cropmax treatments on elongated fruit morphology. The extended fruit length in V1 may be indicative of improved cell elongation and enhanced overall plant growth. The same variant stands out with the widest fruit width at 48.51 mm. This suggests that the combined application of Biochar and Cropmax treatments contributes to broader fruit development, potentially influenced by increased nutrient availability and optimal environmental conditions. These results align with those obtained by Vdovenko et al. (2018).

V1 also records the highest average fruit weight at 46.89 g, highlighting the positive impact of Biochar application and Cropmax treatments on promoting heavier fruits. The substantial weight in V1 suggests enhanced fruit filling, potentially driven by improved nutrient uptake and utilization.

The highest recorded values in V3 for the number of fruits per plant showcase the positive influence of Cropmax treatments in promoting prolific fruiting. Meanwhile, V1's noteworthy values for fruit length, width, and average fruit weight underscore the combined effects of Biochar and Cropmax treatments in enhancing both fruit morphology and weight.

The overall importance of the applied treatments is evident in the consistent and nuanced patterns of total yield across variants (Table 2). While statistical tests may not reveal significant differences, the data underscores the need for a comprehensive understanding of treatment effects and the potential for further refinement to optimize agricultural practices.

Table 2. Tomatillo`s total yield/plant (g)

Variant	Total yield/plant (g)				Significance
	R1	R2	R3	Average	
V1	1620	2114	2176	1970	ns
V2	1560	1685	1729	1658	ns
V3	1587	2101	1387	1691	ns
V4	1111	2530	1123	1588	ns

Each variant exhibits a distinctive pattern in total yield across replicates, reflecting the impact of applied treatments. Even without statistically significant differences, the numerical variations in total yield values indicate that the treatments play a role in shaping overall productivity. In addition, the consistent yield levels across replicates within each variant highlight the reliability of the applied treatments in maintaining a stable and predictable crop output. Consistency is crucial for farmers seeking reliable and reproducible results in their agricultural endeavors. The outcomes concerning the total yield per plant exhibit a degree of similarity to those acquired by Cerri (2006).

Analyzing the recorded values for total soluble solids, titratable acidity, and total dry matter across variants offers valuable insights into the potential effects of applied treatments on fruit quality (Figure 9).

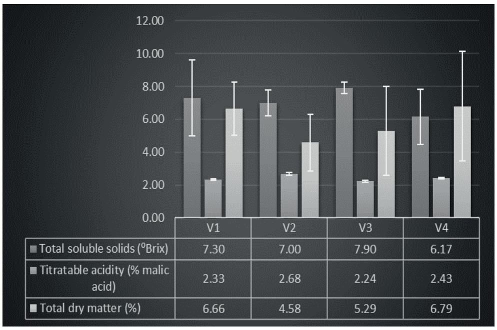

Figure 9. Some qualitative parameters of tomatillo fruits influenced by the nutrient blend

These insights can inform targeted strategies for crop management and contribute to the production of fruits with enhanced sensory attributes and nutritional value. The parameters measured collectively contribute to the overall quality and sensory characteristics of the fruit. Understanding the highest values for each parameter provides insights into the potential for enhancing flavor, acidity, and fruit composition

V3 exhibits the highest total soluble solids at 7.90 °Brix. This elevated level suggests a higher concentration of sugars and soluble compounds in the fruit, potentially indicating improved sweetness and flavor. The increased °Brix in V3 could be attributed to the influence of the applied Cropmax treatments, emphasizing their positive impact on fruit quality.

V2 records the highest titratable acidity at 2.68%. This suggests a higher concentration of malic acid in the fruit, contributing to overall acidity. The Wood vinegar and Cropmax treatments applied in V2 may have influenced the acidity levels, potentially impacting the fruit's taste profile and acidity balance.

Finally, V4 showcases the highest total dry matter content at 6.79%. This parameter reflects the percentage of solid components in the fruit, including sugars, acids, and other compounds. The higher total dry matter in V4, the untreated control group, raises intriguing questions about the natural development of fruit components in the absence of specific treatments. If the outcomes pertaining to the total dry matter content demonstrate commensurability, a discordance emerges in relation to the soluble dry substance, exhibiting an antagonistic disposition in contrast to findings reported by other researchers (Trejo-Téllez et al., 2004; González-Pérez & Guerrero-Beltrán, 2021)

CONCLUSIONS

The application of specific treatments, such as Biochar combined with Cropmax, has demonstrated a consistent positive impact on total plant height, leaf/branch count, and flower/branch count. These findings underscore the efficacy of these treatments in promoting tomatillo`s enhanced growth and morphological development.

Treatments involving Wood vinegar, Cropmax, and their combinations have showcased significant improvements in key tomatillo fruit quality parameters. Notably, elevated levels of total soluble solids (°Brix), favorable titratable acidity (% malic acid), and desirable total dry matter (%) have been observed, emphasizing the efficiency of the applied treatments in enhancing the overall quality of the fruits.

The nuanced variations observed among different treatment combinations highlight the specificity of tomatillo plant responses. Each treatment combination contributes uniquely to plant physiology and fruit characteristics, indicating the importance of tailoring treatments for specific outcomes.

Cropmax treatments have consistently influenced chlorophyll content index (CCI) and anthocyanin content index (ACI) positively. These alterations signify the treatments' efficiency in enhancing photosynthetic processes and secondary metabolite accumulation, contributing to improved plant health and stress response.

The treatments, particularly Biochar application combined with Cropmax, have resulted in robust stem base diameters and optimal branching architectures. These structural enhancements are indicative of the treatments' efficiency in promoting plant strength, stability, and overall architecture.

Distinctly, Cropmax applications have led to increased numbers of fruits per plant and improvements in fruit dimensions, suggesting the efficiency of these treatments in influencing both the quantity and size of the harvested fruits, addressing key aspects of crop productivity.

The analysis of total yield per plant across different variants has provided valuable insights into the efficiency of the applied products. The consistent yield levels observed underscore the robustness and reliability of the studied treatments. The lack of statistical significance should not overshadow the practical importance of the observed trends, as the treatments exhibit a tangible impact on the overall yield.

ACKNOWLEDGEMENTS

The authors acknowledge the Sectorial Plan of the Romanian Ministry of Agriculture and Rural Development, implemented by VRDS Bacau through 6.3.6 and 6.3.20 ADER projects spanning the period 2023-2026.

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