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Conference Paper

Differences in Biomass Accumulation in the Cultivation of Lettuce (*Lactuca sativa L.*) var. Batavia Under Two Greenhouses: Traditional and Heated

Diferencias en la acumulación de biomasa en el cultivo de lechuga (*Lactuca sativa L.*) var. Batavia bajo dos invernaderos: tradicional y climatizado

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Abstract

Lettuce *(Lactuca sativa* L.*)* cultivation shows optimal development in soils with clay-loam or sandy-loam textures, under cool and humid climatic conditions. However, crop yield and quality are negatively affected by the debilitating effect due to high temperatures on plant development. This research aimed to evaluate the performance of the lettuce variety var. Batavia in two types of greenhouses (air-conditioned and traditional), located in the Calpi parish, belonging to the Riobamba canton, province of Chimborazo. During all phenological stages of the crop, measurements and evaluations of morphological and climatic variables were carried out every 15 days. The results obtained were subjected to a 5% Student's T test. The best results were obtained during cultivation in a climate-controlled greenhouse. Compared to traditional greenhouse cultivation, the plant cycle was completed in less time, specifically in 43 days with an average weight of 467 gr, while in the traditional greenhouse, it took 48 days with an average weight of 380 gr. The average height and number of leaves were also higher in the climate-controlled greenhouse, with values of 22.71 cm and a dry matter percentage of 29.87%. The data obtained were subjected to statistical analysis, and it was found that there was a highly significant difference between the means in the two conditions evaluated, with a p-value less than 0.00012. While no significant difference was observed in relation to biometric parameters of the crop versus climatic factors (p-value > 0.05 ns). The results showed a yield of 29.18 t/ha in the air-conditioned greenhouse, whereas in the traditional greenhouse it was 23.76 t/ha, increasing the production and yield of fresh lettuce cultivation by 22.79% in the heated greenhouse compared to the traditional greenhouse.

Keywords: *temperature, relative humidity, curly lettuce, agronomic behavior, yield.*

Resumen

El cultivo de lechuga (*Lactuca sativa* L.), presenta un óptimo desarrollo en suelos con texturas franco-arcillosas o franco-arenosas, bajo condiciones climáticas frescas y húmedas. Sin embargo, el rendimiento y la calidad de la cosecha se ven afectados negativamente por el efecto debilitante que las altas temperaturas ejercen sobre el desarrollo de la planta. La investigación realizada tuvo como objetivo evaluar el rendimiento de la variedad de lechuga crespa var. *Batavia*, en dos tipos de invernaderos (climatizado y tradicional), ubicados en la parroquia Calpi, perteneciente al cantón Riobamba, provincia de Chimborazo.

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Durante todas las etapas fenológicas del cultivo, se llevaron a cabo mediciones y evaluaciones de las variables morfológicas y climáticas, cada 15 días. Los resultados obtenidos fueron sometidos a una prueba T de Student al 5%. Los mejores resultados se obtuvieron en el cultivo bajo invernadero climatizado. En comparación con el cultivo en invernadero tradicional, el ciclo de la planta se completó en un menor tiempo, específicamente en 43 días con un peso promedio de 467 g, mientras que, en el invernadero tradicional tardó 48 días con peso promedio de 380 g. La altura y el número de hojas promedio también fueron superiores en el invernadero climatizado, con valores de 22,71 cm y un porcentaje de materia seca del 29,87%. Los datos obtenidos fueron sometidos a análisis estadístico, y se encontró que existía diferencia altamente significativa entre las medias en las dos condiciones evaluadas, con un *p-valor* menor a 0,00012. Mientras que, en relación de parámetros biométricos del cultivo frente a los factores climáticos no presentaron diferencia significativa (*p-valor* > 0,05 ns). Los resultados arrojaron un rendimiento de 29,18 t/ha en el invernadero climatizado, mientras que el invernadero tradicional un rendimiento de 23,76 t/ha, aumentando en un 22,79% la producción y rendimiento del cultivo de lechuga fresca en el invernadero climatizado, en comparación al invernadero tradicional.

Palabras Clave: *Temperatura, Humedad relativa, Lechuga crespa, Comportamiento agronómico, Rendimiento.*

1. Introduction

The global area dedicated to the cultivation of lettuce has grown by more than one million hectares since 2005 in the main countries of global growth. The United States is the main producer, contributing 16% of world lettuce production (1). he North American bloc has decreased its participation in total production due to its 6% decline in the area dedicated to cultivation and the productive growth of other countries such as China (77%) and Iran (511%) (2). Spain and Italy are the main European producers. These countries contribute to the world total of 868,203 tons (3.5%) and 364,843 tons (1.4%), respectively. They are followed, in order of importance, by France and the United Kingdom. The Asian and European continents concentrate 80% of world production, while the American continent accounts for 27% (3) .

All lettuces grown today are derived from the humble Lactuca sativa, a wild lettuce that has morphological characteristics such as smaller, harder leaves. It has a pungent flavor and small yellow flowers, which grow like weeds in Europe and Asia. From an agricultural point of view, it is a vegetable suitable for a cool climate. (1).

World lettuce production was 27,660,187 tons, obtained on a harvested area of 1,226,370 hectares, so the average yield was 22.6 tons per hectare, according to the year 2021.(4).

The cultivation of lettuce (Lactuca sativa L.) in Ecuador presents a great demand for its production. Successfully projecting itself to both local markets and large international

markets due to its recognized quality. This motivates more and more farmers to venture into this important productive line. (5).

In the country, this crop is produced by small producers, accounting for 83% of the national production. This is for the country's internal consumption because it can be done under different conditions, such as hydroponics, mulching, and open and closed fields, which is how it is traditionally grown. (6).

Over the years, vegetable production has had high yield and quality, and the cultivated area of this vegetable has increased (7). On the one hand, the introduction of new cultivars has brought the attention of farmers from different provinces to their production and marketing (8). Currently, it is about looking for new production alternatives, such as technical greenhouses or new irrigation systems, to facilitate increased yield. (9).

Its distribution includes the dry and temperate valleys of the Sierra. In certain places, it can be located in higher parts but protected from frost and with dry periods of more than three months. In areas where there is precipitation of 400–600 mm during the crop cycle, 12 hours of daily light, and a temperature between 14 and 18 °C. It also requires soil with good drainage and a pH of 5.5 to 7.0. The determination of performance and production in different systems is appropriate (10). Therefore, the provinces most commonly associated with this type of cultivation are:

- Tungurahua, with 3,256 tons in an area of 640 hectares
- Chimborazo, with 2,560 tons in an area of 366 hectares
- Pichincha, with 548 tons in an area of 68 hectares
- Azuay, Carchi, Loja, and Imbabura have a range of 45 to 49 hectares.

In recent years, it has been grown under greenhouses for export, and markets with very good potential have opened during the commercial window. In the country, there are 1,145 hectares of lettuce with an average yield of 7,928 kg per hectare, according to the Ministry of Agriculture. Of the total production, 70% is Creole lettuce, while 30% is varieties such as red, roma, or salad. (11).

Regarding the biomass of this crop, it is accumulated and distributed by their genotypic characteristics, which are usually easily affected due to the environment, especially their interaction. Depending on the growth kinetics and distribution rate preceded by leaf area, climate, and nutrient availability (12). The accumulation of heat inside a greenhouse causes heating of the root zone of the crops; therefore, the accumulation of biomass and the acquisition of nutrients in lettuce increase (13). Therefore, the present study was carried out to determine the gain in yield and biomass when comparing a traditional greenhouse with a climate-controlled one.

2. Materials and methods

The present research was carried out in the greenhouses located on the *Maquita Cushunchic Fundación Comercializado como Hermanos* premises, which belong to the Calpi parish, Riobamba Canton, Province of Chimborazo, Ecuador. A transplant was carried out on four beds measuring 32m x 1m in each greenhouse, with a distance of 35 cm between plants and rows of 50 cm. A double-tape drip irrigation system of 1.6 lt/h was designed, with a distance between drippers of 15 cm. By establishing an irrigation schedule in advance for each phenological stage that the crop completed, in the end, the water footprint corresponding to each greenhouse was determined. The factors inside (temperature, relative humidity) were controlled by means of sensors (Datta Loogers), which were programmed to record data every hour. While soil moisture was measured using 30 cm-deep tensiometers established in the middle of each greenhouse, this data was recorded each day. Biometric parameters such as plant height were measured from their base to the apical part with a measuring tape. The number of leaves was counted visually; this was done every 8 days. Once the plants were harvested, the yield projection was carried out. In the same way, 20 plants were taken at random and weighed to obtain a wet weight (ph). They were chopped to place them in trays, transferring them to an oven for 24 hours at 120 °C. In the end, a dry weight (ds) was obtained, and applying the corresponding formula, dry matter was obtained:

$$\% \text{ Moisture} = \frac{wet\ weight\ (ph) - Dry\ weight\ (ps)}{wet\ weight\ (ph)} \text{ x100}$$

$$\%\text{Dry matter} = 100 - \%Moisture$$

2.1. Heated Greenhouse

The heated greenhouse is located in the Calpi parish, and has unique characteristics, different from other greenhouses in the province, including:

Daytime Operation: If the temperature exceeds 18–20 °C, the fans and windows are automatically activated, turning on and opening to evacuate the excess. Otherwise, if the temperature begins to drop below the set range, the fans automatically turn off and the windows close to maintain the appropriate temperature, at any time of the day.

Nighttime Operation: Starting at 6 p.m. in the afternoon, the heat pumps inside the greenhouse began to operate, and the windows automatically closed until the next morning. At the top, a thermal buoy was implemented, which inflated at the same time, covering the entire space to preserve the heat inside between 4 and 8 °C throughout the night until the next morning, when it turned off automatically.

2.2. Traditional Greenhouse

The traditional greenhouse is built of metal and is the greenhouse that we find in most of the horticultural plantations in the province. It has the following characteristics:

Daytime Operation: Since it did not have any of the equipment that was inside the heated greenhouse, the windows had to be opened manually, throughout the day.

Nighttime Operation: Starting at 6 pm in the afternoon, the windows were closed manually until the next morning, when they were opened again.

3. Results and discussion

3.1. Duration of phenological stages (days) of lettuce cultivation

Statistically, a comparison was made between the duration in days of the growing cycle in a climate-controlled greenhouse environment and in a traditional greenhouse. The results indicated that there are no significant differences between both environments, with a p-value of 0.615 (Table 1), because the data correspond to a population with a normal distribution. At the end of the phenological phase of the crop, it was observed that the climate-controlled greenhouse crop reached maturity after 43 days, while the traditional greenhouse crop took 48 days (Figure **1**).

Tabla 1

Cycle duration (days) Student's T test of the lettuce crop (Lactuca sativa L.) var. Batavia in both types of greenhouses.

Independent Samples T Test		
Variables	**Heated Greenhouse**	**Traditional Greenhouse**
Mean	10,75	12,01
Variance	10,92	11,33
Observations	4	4
t-statistic	0,529	
x of conditions	46 days	
Difference between treatments	5 days	

3.2. Dry matter percentage

The dry weight of the crops is an important factor for the composting process since it determines the amount of organic matter available for decomposition and transformation into compost. According to the results shown in Table 2, statistically significant

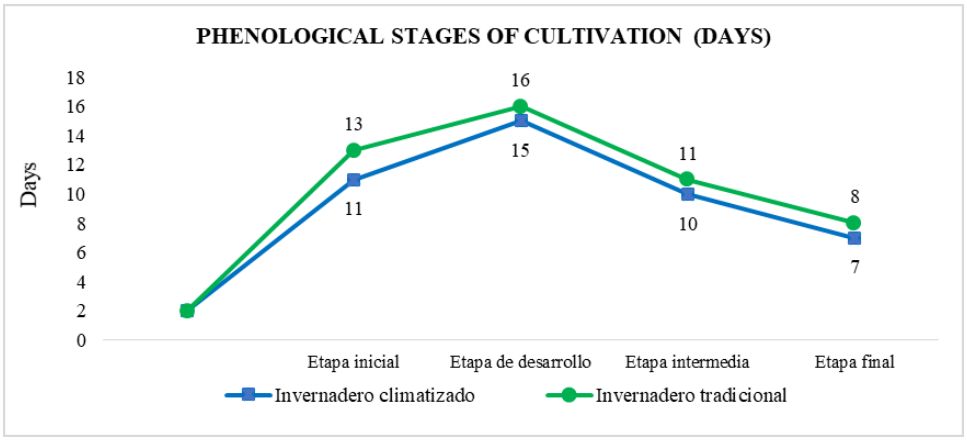

Figura 1

Duration of the phenological stages (days) of the lettuce (Lactuca sativa L.) var. Batavia crop in both types of greenhouses.

differences were found in the percentage of dry matter in the aerial part of the crop in both environments, with a with a p-value of 0.027. The average percentage of dry matter in the heated greenhouse environment was 29.87%, while in the traditional greenhouse it was 22.81%. Therefore, the two environments were grouped into two groups, A and B, as shown in Figure **2**.

Tabla 2

Student's T test to obtain the percentage of the lettuce crop dry matter (Lactuca sativa L.) var. Batavia in both types of greenhouses.

Independent Samples T Test		
	Heated Greenhouse	**Traditional Greenhouse**
Mean	29,87	22,81
Variance	142,12	46,00
Observations	20	20
Difference between treatments	7,06 %	
t-statistic	2,302	
p-value	0,027	

3.3. Yield

The fresh weight of crops is an important factor that affects the quality and properties of agricultural and horticultural substrates. In the case of the lettuce crop, an average fresh weight of 467 g was recorded in the heated greenhouse, classifying it in the "A" range. While in the traditional greenhouse, an average fresh weight of 380 g was obtained,

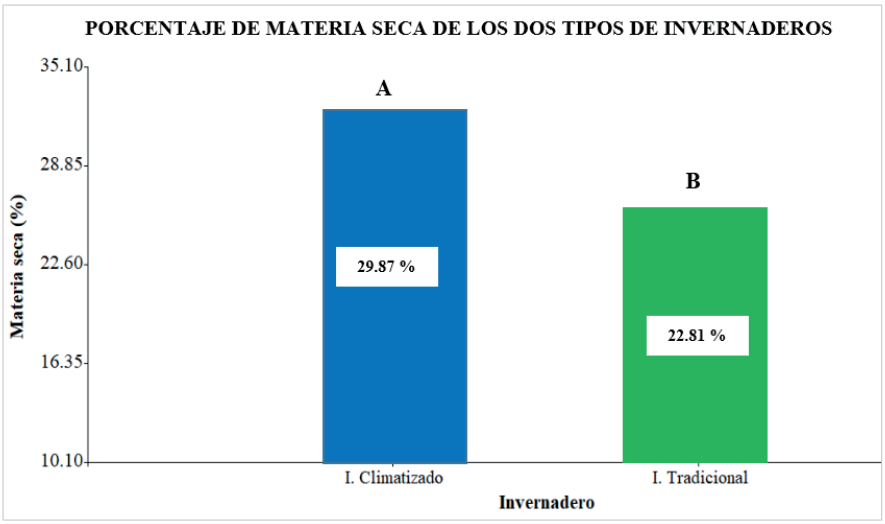

Figura 2

Dry matter percentage of the lettuce crop (Lactuca sativa L.) var. Batavia from each greenhouse.

placing it in the "B" range. Student's T test analysis yielded a highly significant p-value (p-value <0.00012) (Table 3). Indicating that there is a significant difference in the fresh weight of lettuce between the two types of greenhouses. These results suggest that the growing environment, in particular temperature and humidity, can influence the fresh weight of lettuce and, therefore, the quality and properties of the resulting substrate.

Tabla 3

Student's T test to obtain the crop yield of Lactuca sativa L. var. Batavia in both types of greenhouses.

t test for independent samples		
Variables	**Heated Greenhouse**	**Traditional Greenhouse**
Mean	466,83	380,19
Variance	13305,29	20114,57
Observations	100	100
t-statistic	4,739	
Difference between treatments	5,42 t/ha	
p-value	< 0,00012	

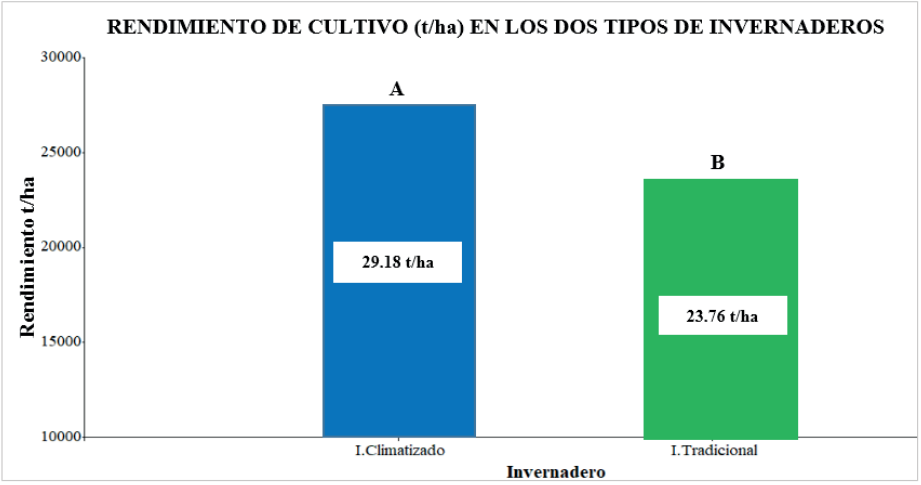

Figura 3

Crop yield of lettuce (Lactuca sativa L.) var. Batavia (t/ha) in both types of climate-controlled and traditional greenhouses.

3.4. List of biometric parameters of the lettuce crop (Lactuca sativa L.) var. Batavia versus temperature, relative humidity, and soil moisture factors.

Table 4 presents the results of the biometric parameters of the crop obtained in both different climatic conditions inside the structures. It is observed that the crop's height and number of leaves in the climate-controlled greenhouse presented significant differences in relation to soil humidity (kPa), with a p-value of 0.045. However, the other parameters and the traditional greenhouse did not show significant differences. These results suggest that soil moisture is an important factor in crop growth and development in a climate-controlled greenhouse and that it can have a significant impact on crop height and leaf number.

4. Discussions

When carrying out the respective tests to obtain the percentage of dry matter in the air-conditioned greenhouse, it was possible to obtain a percentage of 29.87%. While in the traditional greenhouse, a percentage of 22.81% was obtained, there was a numerical difference of 7.06% in dry matter between the two treatments (Figure **3**). According to Vega (14), inside the roofs there is a microclimate where the environmental factors are different compared to those outside. Therefore, it affects the development of the crop in a gradual manner, and there may be greater or lesser development of the crop.

Tabla 4

Correlation and linear regression analysis of biometric parameters against the factors under study in both climate-controlled and traditional greenhouses.

Biometric parameters	Factors under study	Regression Coefficient "b" (p-value)	Correlation Coefficient "r"	Coefficient of Determination "R^2"
Heated Greenhouse				
Plant height	Temperature	0,281	0,529	0,280
Plant height	Relative humidity	0,627	-0,254	0,065
Plant height	**Soil moisture**	**0,045**	**0,779**	**0,607**
Number of leaves	Temperature	0,260	0,547	0,300
Number of leaves	Relative humidity	0,644	-0,242	0,058
Number of leaves	**Soil moisture**	**0,045**	**0,798**	**0,637**
Biometric parameters Factors under study **Regression Coefficient "b" (p-value) Correlation Coefficient "r" Coefficient of Determination "R^2"**				
Traditional Greenhouse				
Plant height	Temperature	0,855	0,097	0,009
Plant height	Relative humidity	0,978	-0,015	0,0002
Plant height	**Soil moisture**	0,365	0,455	0,207
Number of leaves	Temperature	0,944	0,037	0,001
Number of leaves	Relative humidity	0,778	-0,148	0,022
Number of leaves	**Soil moisture**	0,332	0,482	0,233

Tabla 5

No.	COMENTARIOS DEL 1er REVISOR	MODIFICACIONES EFECTUADAS
1	Colocar todos los decimales con "coma", y no con punto.	Se realizó los cambios sugeridos en el formato del separador de decimales.
2	Añadir la palabra referencias	Se incorporó la palabra Referencias al inicio del listado de consultas bibliográficas.

Tabla 6

No.	COMENTARIOS DEL 2do REVISOR	MODIFICACIONES EFECTUADAS
1	Verificar el cumplimiento de acuerdo a la guía de autor.	Se verificó el documento con base a las especificaciones de la guía de autor, por lo que declaramos que cumple con dichas especificaciones.
2		

Although temperature and relative humidity did not present significant differences in both greenhouses, soil humidity did influence the height of the plant and the number

of leaves. According to Prados, Sonoma, (15) (16), plants demonstrate physiological and morphological changes throughout their cycle. When they are under this type of cover due to the climatic conditions inside and the management of the irrigation system. All in its optimal range. If the temperature is controlled, the crop can shorten its development time by directly acting on the growth rate, the number of leaves, the height, and other quality standards.

If plants are planted close together or have dense foliage, moisture can be trapped, resulting in another microclimate. This may be the reason that the plants in the heated greenhouse had better development compared to those in the traditional greenhouse that did not. According to Martínez M. FE., Garces V. GA., and Vega (7) (14), as constant changes in temperatures and relative humidity prevail inside the structures, the crop needs more inputs (nutrients, water, solar radiation, etc.). Both to maintain its metabolism and be able to avoid damage to the tissues, which can also slow down the development of the crop. Therefore, and as a result, the morphological differences could be due to these reasons.

The lettuce crop recorded an average fresh weight of 467 g in the climate-controlled greenhouse, while in the traditional greenhouse, an average fresh weight of 380 g was obtained. According to Carmen (12), lettuce is the most efficient crop in generating biomass since it reached 271.0 grams after 120 days, concluding that this crop is highly efficient in generating total biomass.

According to García (9), fresh weight yields in lettuce varieties can reach 22.50 to 30.00 t/ha, with head weights of 0.5–1 kg. Production depends on the size of the plants at the time of collection and the number of plants per m2. According to Salinas (17), a good yield is considered when between 3 and 5 kg per m2 are collected, obtaining 8 to 15 units per m2. Therefore, the results obtained in the test cover these proposed ranges and are within them.

5. Conclusion

The best yield per hectare was achieved in treatment 1, which corresponds to the heated greenhouse, obtaining 29.18 t/ha. The treatment with the lowest yield was 2 corresponding to the traditional greenhouse, obtaining 23.76 t/ha. The fresh weight of lettuce can affect the water-holding capacity and drainage capacity of the substrate. Therefore, it is essential to measure the fresh weight of the lettuce and adjust its quantity in the substrate mixture to achieve a balanced and high-quality substrate.

The lettuce seedlings with the best agronomic characteristics were obtained in the heated greenhouse. By controlling the factors of temperature, relative humidity, and

irrigation system, it was possible to maintain an optimal range during the day and night with its automation. Standing out for reaching the greatest number of leaves, shortening the harvest time, plant height, better vigor, better development, dry matter, and yield, unlike the traditional greenhouse that had lower parameters.

Greenhouse lettuce production generates a large amount of crop residue that can have a significant impact on the environment if not managed properly. These residues include lettuce leaves and roots, as well as any other plant material left over after harvest. The accumulation of this waste can attract pests and diseases, and its decomposition can release greenhouse gases and contaminate nearby soil and water. However, this waste also represents an opportunity to produce biofuels, fertilizers, and other useful products. Many farmers have implemented sustainable waste management practices, such as composting and biogas production, to minimize environmental impact and harness the value of crop residues. It is important to continue researching and developing new innovative and sustainable ways of managing lettuce harvest waste in the greenhouse to achieve more responsible and efficient production.

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