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Morphophysiological Indicators of Cabbage (*Brassica oleracea* L. var. capitata) Planted Inside and Outside Greenhouse, under Ecuadorian Amazon Conditions

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Authors' contributions

This work was carried out in collaboration between all authors. Author RAP designed the study, wrote the protocol, and wrote the first draft of the manuscript. Authors JDB, YRG and SSR managed the literature searches, analyses of the study performed the structural equation modelling and discuss the conclusion. All authors read and approved the final manuscript.

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ABSTRACT

The Ecuadorian Amazon is the poorest in the country, particularly the province of Pastaza is the largest and one of the least developed in the field of agriculture. The Universidad Estatal Amazónica initiated a research program to evaluate the adaptation of different horticultural species plants to conditions in the region, in order to contribute to food sustainability. This study analyzed the behavior of cabbage crop variety Gloria, planted under controlled conditions in the greenhouse and outside it. The morphological, physiological and crop production indicators were evaluated in both planting conditions. The results showed that the cultivation offers better morphological and physiological indicators when it was sown in the greenhouse; however the best production indicators and agricultural yield was obtained in planting outside the greenhouse, indicating that desirability of establishing this crop in the Ecuadorian Amazon without sow in the greenhouse.

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1. INTRODUCTION

Pastaza is undoubtedly the largest province of Ecuador and situated in the Amazon Region, and probably the greatest contrasts. It has an area of approximately 29773 km^2, equivalent to 66% of the Amazon Region and 12% of the national territory. Pastaza province is located in the center of the Ecuadorian Amazon region, including the geographic coordinates 1°10 south latitude and 78°10 west longitude; 2°35 south latitude and 76°40 west longitude. One of the climatic conditions of this province is the humid and tropical, on the other hand, the CIPCA, which features located between 200 and 800 m, registering an average annual temperature between 22 and 26°C, an annual rainfall of 2000-4000 mm [1].

Studies in cabbage crop, with density of 22222 plants per hectare, reported values of leaf area of 0.77 m^2 [2]. These authors also reported values of leaf area index between 1.49 and 3.83.

A study in cabbage carried out by a research team [3] has shown a leaf area index of 5.17, after 68 days of transplanting. And a 65.3% of the biomass accumulated in the leaves considered as the marketable cabbage head, 28.4% in the stem and 6.3% in the root. Another research obtained a biological plant yield of 100.2 g with a density of 40000 plants per hectare [4]. In another study, it was found that a maximum and minimum weight of 0.97-1.56 kilograms per plant respectively [5].

In another experiment in cabbage, with planting density of 40000 plants per hectare, reported values cabbage head weight between 0.72 and 1.62 kg [6].

In studies conducted in nine hybrid cabbage, in a total of 25000 plants per hectare, average yields from 9.4 to 29.6 ton/ha were reported [7].

Agricultural production in the region is centered on two productive ways. Agricultural Production Units that can be of different sizes and agricultural activity and orchard (“chakra”), usually small and dedicated to agricultural crops.

In the Amazon region of Ecuador, particularly in province of Pastaza, there is little culture of consuming plants and vegetable species and is based on climatic and soil conditions of the region are not suitable for these crops. The vegetables consumed come from the mountain and coast which makes selling prices are high.

For these reasons, it was proposed to conduct a study of diversification of production systems with the inclusion of vegetable species. In the project 17 horticultural species plants were sown inside and outside the greenhouse. This study presents the results obtained in cabbage (*Brassica oleracea* L. var. capitata).

2. MATERIALS AND METHODS

The study presented in this manuscript was done at the Center for Research, Graduate Studies and Conservation of Amazonian Biodiversity (CIPCA) belonging to the Amazon State University (UEA) is a reserve of 2800 ha, located in Canton Arosemena Tola of the Napo Province, whose location geographic is 01˚ 11'29 " south latitude and 77°51' 25" east longitude, at an altitude of 550 meters for which areas extending between the Napo and Pastaza provinces in the Amazon region of Ecuador. According to the data processed in the weather station: the average monthly temperature is 23.8°C, with warm humid climate with an annual rainfall of 3538 mm and irregular topography (Navarrete, H. Universidad Estatal Amazónica, personal communication, 2014).

Gloria variety of cabbage was grown under greenhouse and outside it. A seedbed was established in germination trays on February 20, 2014, the transplant was performed at 38 days after seed germination when seedlings were appropriate conditions for this.

The transplants were collected on March 30 at a distance of 0.80 x 0.40 meters to 31250 plants/ha. Organic fertilizer (compost) was applied at a dose of 5 ton/ha which was incorporated into the soil before transplanting. At 15 days of germination, foliar fertilizer was applied (Metalosate Crop Up) at a dose of 1 cc/liter and repeated at 30 and 60 days.

The necessary humidity inside the greenhouse was maintained with a plastic watering and no water was applied to planting outside the greenhouses, using rainwater plant development rather frequent in this region.

At 25 and 72 days after transplant (dat) they were evaluated for morphological parameters such as plant height (cm), stem thickness (cm) measured 10 cm above soil line, leaf number, length and width (cm) of leaves. The leaf area index (LAI) for cultivation was determined according to planting distance used. Dry matter by vegetative organs was evaluated in two stages of crop development and major physiological indicators such as net assimilation rate (NAR) [8] for the interval between 25 and 72 days after transplantation were calculated. This shows the amount of dry matter produced per unit of leaf area in a day's work, expressed in g/m^2/day. For the calculation, the following formula was used:

$$NAR = \frac{2\cdot(P_f - P_i)}{(A_f - A_i)\cdot(t_f - t_i)} \quad (1)$$

where: P_f is total dry weight of the72 days, P_i is the total weight of dry matter at 25 days, A_i is leaf area at 25 days, leaf area A_f is72 days, t_f at 72 days emergency, t_i 25 days of emergency.

The Photosynthetic Potential (PhP) [8] was calculated using the 2 values of measured leaf area, using the following formula:

$$PhP = \sum\left(\frac{A_f + A_i}{2}\right)\cdot t \quad (2)$$

where: t is time in days, between one measurement of leaf area and the following

Foliar Productivity Index (FPI) was obtained by dividing the dry weight of cabbage head at harvest photosynthetic potential.

Finally the biological yield [BY = total dry matter production per plant (vegetative and reproductive organs)] and economic yield [EY = dry matter production of cabbage head per plant] were determined to obtain harvest index [HI = EY/BY] [8]. Cabbage head weights per plant and crop yield (kg/m^2) were also determined. Phytosanitary assessments were made during crop development.

3. RESULTS AND DISCUSSION

3.1 Morphological Variables: Plant Height (cm), Stem Thickness (cm), Number of Leaves

The Table 1 showed data at 25 dat on the cabbage plants that did not differ statistically in plant height and number of leaves, when they were planted in a greenhouse and outside it, although numerically the plants that were in the greenhouse had shown higher values. At 72 dat, there was a greater plants height in greenhouse, than the plants that grew outside it, but without statistical difference. The same result was obtained for the number of leaves. The stem thickness was greater at 25 dat in the plants growing in the greenhouse compared with the ones that grew outside it, with significant difference, although it was not in this way at the 72 dat, where virtually the plants in both conditions had stems of equal thickness.

3.2 Leaf area and Leaf Area Index of Cabbage

Plants grown in the greenhouse showed higher mean values of leaf area and leaf area index at 25 and 72 days after transplant especially was found statistically significant difference in LAI at 25 dat (Table 2 and Fig. 1). The values of LAI (leaf area of the plant to the surface rightful soil as planting distance) at 25 dat corresponded to those obtained by a previous group of research, and were lower than 2. At 72 dat the leaf area index has a mean value of 3, 69 in the greenhouse and outside 2, 83, both lower than those reported by the group mentioned before [3], where LAI reached 5.17 at 68 dat.

Table 1. Mean values of morphological variables cabbage, inside and outside greenhouse

Treatments	Height of plant (cm)		Stem thickness (cm)		Number of leaves	
	25 dat	72 dat	25 dat	72 dat	25 dat	72 dat
Greenhouse	8.5 a	37.3 a	0.97 a	2.3 a	10.4 a	13.7 a
Outside	6.5 a	33.0 a	0.55 b	2.0 a	10.0 a	15.3 a

Different letters in the same column denote statistical difference for p ≤ 0.05, Tukey test

Table 2. Mean values of leaf area and leaf area index cabbage, inside and outside greenhouse

Treatments	Leaf area (m^2)		Leaf area index	
	25 dat	72 dat	25 dat	72 dat
Greenhouse	0.26 a	1.18 a	0.83 a	3.69 a
Outside	0.12 a	0.90 a	0.37 b	2.83 a

Different letters in the same column denote statistical difference for p ≤ 0.05; Tukey test

In the beginning of the cabbage crop, the leaves had greater penetration of photosynthetically active radiation through the sunless leaves of the plant. As the IAF peaks in the upper third leaves and intermediate compacted to form the head or cabbage (agricultural cabbage head), which eventually harvest; leaves the lower third pick of the direct radiation and upper thirds capture diffuse radiation. At low values of IAF, the leaves form right angles to intercept light.

3.3 Percentage and Dry Matter Accumulation by Vegetative Organs of Cabbage

The levels of dry matter in root, stem and leaves of cabbage plants at 25 days after transplant (Fig. 2) corresponded to those reported by related research [9], were slightly higher in greenhouse plants and statistically not differ from plants growing outside the greenhouse, but in all cases the percentages of root dry matter was significantly higher in all outside the greenhouse plants.

At 72 days after transplant the quite different situation was observed, percentages of dry matter practically equal to organs stem, leaves and cabbage head for the two treatments (Fig. 3). It was observed that the root had a higher percentage of dry matter in greenhouse plants over plants grew outside the greenhouse conditions ($P \leq 0.05$). This can be explained by weather conditions where plants were grew, as in the greenhouse not receive as much water and therefore go deeper roots and likewise are strengthened accumulating more dry matter. The dry matter accumulation in different organs was not uniform at 72 days after transplant. The roots did not differ statistically and show very similar values, slightly higher greenhouse plants; however in stems and leaves no statistical difference for plants in greenhouses in relation to plants in the open. This was not occurred equally in the cabbage head that manage to accumulate more dry matter that were in the open. The highest value of dry weight was found in the leaves and farm cabbage head, however leaves were compact. These results are consistent with those reported by another team of research [3], where, more than 65.3% of the biomass accumulated in the leaves of cabbage which was equal to marketable size, 28.4% in the stem and 6.3% in the root.

3.4 Indicators of Growth, Net Assimilation Rate (NAR), Photosynthetic Potential (PhP) and Foliar Productivity Index (FPI) of Cabbage

Net Assimilation Rate observed in the present study was approximate to those reported before [4], and values are acceptable to the cabbage in these weather conditions. Fig. 4 shows that a slight increase in NAR values for plants that were grew in the outside, indicating that under these conditions the plants received more light and water for crop growth and this caused high amount of dry matter production per unit of leaf area in a day's work, although statistically no difference found between both treatments. However the Photosynthetic Potential expressing the average leaf area of living leaves had worked throughout the lifecycle of the plant, was numerically greater in plants grown in the greenhouse but without statistical significance. This might be due to a compensatory effect of growth and development of vegetative plant organs that developed a smaller root system outside the greenhouse under the given amount of rain almost daily. This is because plants have not had the need to deepen its roots in search of water and were maintained on the surface. Under these conditions the plants developed less foliar apparatus. Regarding Foliar Productivity Index (FPI), it was greater in plants grown outside differing statistically from those grown in the greenhouse (Fig. 4). The FPI represents the weight of dry matter of the cabbage head produced per unit area of leaf blade per day.

3.5 Biological, Economic Yields and Index Cabbage Crop

The biological performance that represents the total dry matter production per plant (vegetative and reproductive organs) was higher in plants grown in the greenhouse and 72 dat presented statistical difference in relation to producing plants in the open, but not 25 dat. This may be explained on the leaf area regarding a possible compensatory effect of plant organs. The values obtained at 72 dat were 97.2 and 120.4 grams for outside the greenhouse and greenhouse, respectively (Table 3), were similar to those reported by a research [4] before with 100.2 g per plant with 40000 plants per hectare. The economic performance that expressed the dry matter produced by the agricultural cabbage head of the plant was higher outside the greenhouse plants over plants grew inside the greenhouse ($P \leq 0.05$).

a **b**

Fig. 1. Cabbage, variety Gloria, a) outside b) Greenhouse (Photo by author)

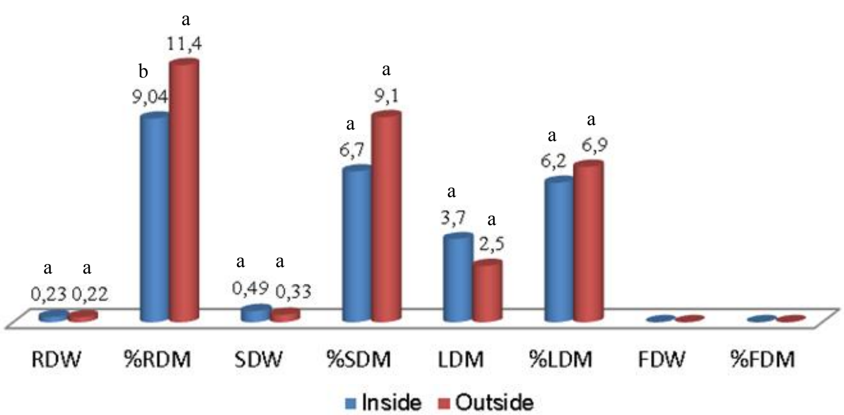

Fig. 2. Percentage and dry matter accumulation of vegetative organs of cabbage, at 25 dat
Different letters in the same column denote statistical difference for p =.05; Tukey test

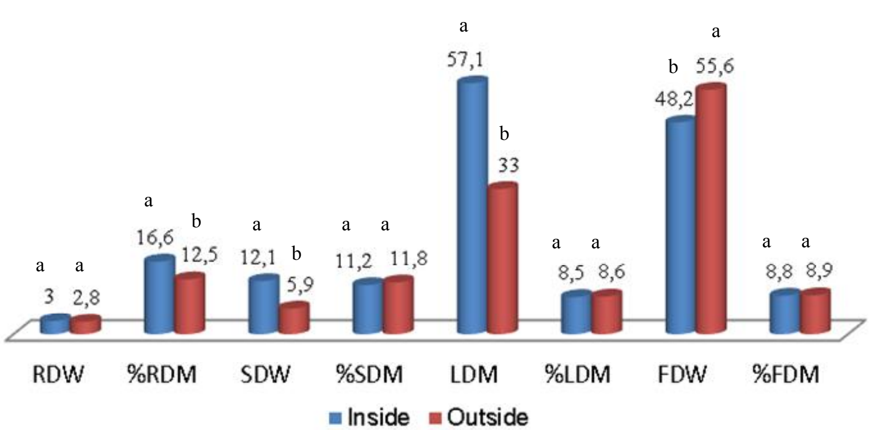

Fig. 3. Percentage and dry matter accumulation of vegetative organs of cabbage, at 72 dat
Different letters in the same column denote statistical difference for p ≤ 0.05; Tukey test

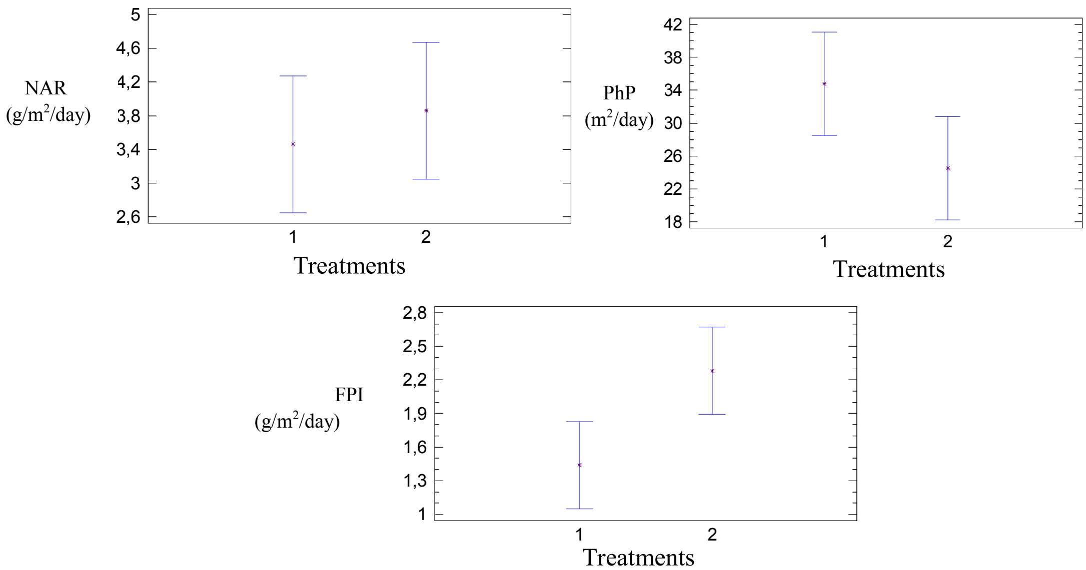

Fig. 4. Variation of the growth indicators cabbage, inside (1) and outside (2) greenhouse
$p \leq 0.05$; Tukey test

Because, the plants under greenhouse had more leaves and increased leaf area, but this did not translate proportionally compact leaves forming cabbage or head, so cabbages formed inside the greenhouse were smaller and lighter (Fig. 5). The solids content of agricultural cabbage head outside the greenhouse was slightly higher as weight of dry matter per cabbage head and this made the biological performance was also higher. When we analyzed the harvest index that expressed the relationship between biological and economic returns was higher outside the greenhouse plants with value of 0.6, nutritionally good for cabbage and indicated that 60% of dry matter produced by the plant cabbage under these conditions corresponds to its agricultural cabbage head.

3.6 Weight of Cabbage Head per Plant and Yield Agricultural of Cabbage

The plants outside the greenhouse showed more weight cabbages, were significantly differ from inside and this makes outside the greenhouse also has a higher crop yield with over plants in the greenhouse ($P \leq 0.05$). The average weight of cabbage head per plant was 0.89 and 1.3 kg per plant in the greenhouse and outside the greenhouse, respectively. These given results were encouraging for growing cabbage because the tendency of consumers to buy medium cabbage. The values obtained are consistent with those reported before [5], with 1.56 maximum and minimum weights of 0.97 kilograms per plant and lower than [10] in the resultant weight range of 1.77 to 2.43 kilograms per cabbage head in studying 6 varieties of cabbage (Fig. 5).

Crop yield was higher outside the greenhouse with values of 7.8 kg/m^2 (78 ton/ha) and statistical significant to that obtained in the greenhouse of 5.3 g/m^2 (53 ton/ha) and are in the field of those reported recently [5], 53.5 ton/ha minimum and 79.6 ton/ha or less, and are very similar to those exhibited in previous research [11], and higher than those obtained by other researchers [12,13].

Table 3. Variation of the biological, economic and harvest index of the variety of cabbage yields

Treatments	Biological yield (g)		Economic yield(g)	CropIndex
	25 dat	72 dat	72 dat	72 dat
Greenhouse	4.4 a	120.4 a	48.2 b	0.4 b
Outside	3.1 a	97.2 b	55.6 a	0.6 a

Different letters in the same column denote statistical difference for $p \leq 0.05$, Tukey test

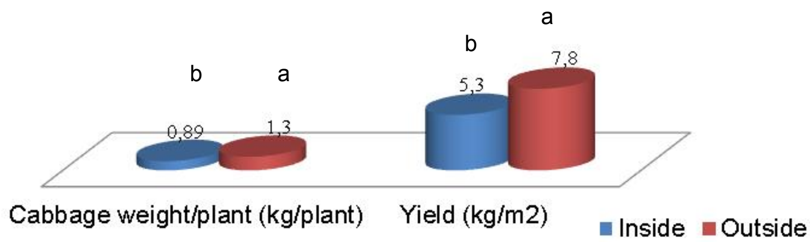

Fig. 5. Weight of cabbage head per plant and crop yield of cabbage
Different letters denote statistical difference p ≤ 0.05; Tukey test

Crop yield was higher outside the greenhouse with values of 7.8 kg/m^2 (78 ton/ha) and statistical significant to that obtained in the greenhouse of 5.3 g/m^2 (53 ton/ha) and are in the field of those reported recently [5], 53.5 ton/ha minimum and 79.6 ton/ha or less, and are very similar to those exhibited in previous research [11], and higher than those obtained by other researchers [12,13].

3.7 Plant Health Behavior of Cabbage

No pest attack was detected during crop development in any of planting conditions.

4. CONCLUSION

The cultivation of cabbage showed better indicators of morphological and physiological planting in Greenhouse. The productive agricultural performance indicators were higher in planting cabbage at field. Planting cabbage under open conditions of the Ecuadorian Amazon area is feasible.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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