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Original Research

Evaluation of the Control of Environmental Variables in a Pine Seedling Greenhouse

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Abstract

The objective of the research was to evaluate the control of environmental variables that allows obtaining a favorable environment inside a greenhouse for the development of *Pinus radiata* seedlings. A controller was implemented inside the greenhouse to maintain the variables in preset ranges: temperature from 19.0ºC to 25.0ºC; soil humidity from 50% to 100%; ambient humidity from 70% to 90% and illumination at levels greater than 450 lux. The control algorithm was implemented in the PIC 18F4550 microcontroller, as control actuators were used: a fan-exhaust fan and air heater for temperature; solenoid valves for soil and ambient humidity; LED lamps for illumination. As a result, the environmental variables controller, when tested for 24 hours for 10 days, maintained on average: temperature at 21.54ºC; soil humidity at 75.09%; relative humidity at 79.32% and illumination in the absence of sunlight at 451.62 lux. Likewise, it was found that the DQI of *Pinus radiata* seedlings of the average control group was 0.433 and the experimental group had an average DQI of 0.571; when evaluating the normalized DQI for both groups, a significant difference greater than 5% was obtained, with the t-test for two-tailed independent samples, with the p-value = 0.002, which is less than the significance level alpha = 0.05. Therefore, it is concluded that the controller generated a favorable environment for the development of the *Pinus radiata* seedlings of the experimental group, having a high possibility of survival when transferred to the final field.

Keywords: *Pinus radiata*, humidity control, temperature control, light intensity, environmental variables

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Introduction

In the central Andes of Peru there is an accelerated deforestation of the little existing vegetation, which in rainy seasons generates floods, landslides and increased frost damage, further aggravating with climate change [1]. Likewise, population growth, mining activities, construction of communication routes, increase in land for cultivation, among other anthropic activities, accelerate deforestation [2]. The climatic variables represent the factors that determine the development and the amount of production in the different forest plantations, the quality of the soil is another important factor for the establishment of these in a seedling state [3, 4]. Locally, the definitive forest plantations are established in places without vegetation cover, mainly in the foothills of the mountains to prevent soil erosion and improve air quality for the inhabitants of surrounding places, so the seedlings must be vigorous for its successful adaptation.

Various regions of the Peruvian highlands are suitable for afforestation; however, in the definitive field, pine plants have a mortality rate that exceeds 50% [5]; mainly due to the fact that seedlings from nurseries or greenhouses do not have adequate quality for their survival [6]. The adequate humidity affects the different plantations from the germination of the seeds, as is the case of the pine species, which is evidenced in the study carried out by Sevik et al. [7] where they found that most pine species are susceptible to water stress below -6 bar, reducing their germination to 30% of the control group.

Likewise, in various investigations it was found that the first days of life of the seedlings of the different species of pines are key to their survival [8], for which a controlled temperature, soil humidity, lighting and environment are necessary to obtain quality seedlings; managing to generate barriers to prevent various diseases and against natural predators existing in uncontrolled environments [9].

A greenhouse is a facility with special characteristics conditioned for the production of plants or seedlings, where environmental conditions are managed in such a way as to neutralize the effects of climatic phenomena, generating favorable environmental conditions for their development [10-12]. In greenhouses it is also possible to control the quality of the water, which can even be gray water recovered for irrigation [13].

Several studies indicate that greenhouses with controlled environmental variables are one of the great options to supply quality seedlings, guaranteeing their survival and symbiotic adaptation to the definitive development field [14, 15]. Being one of the great challenges the control of environmental variables, such as: temperature, soil humidity, ambient humidity and lighting, each of them at certain intervals, for the production of *Pinus radiata* seedlings [16, 17]. On the other hand, lighting control allows the management of plant growth in low light environments, the light source used is of the red and blue LED type with different wavelengths [22].Greenhouses that include sensors and actuators to control environmental parameters allow monitoring and control. To fulfill this function, they are based on microcontrollers that are part of the hardware module and contain a control algorithm that is the software of the application system [18].

To determine the quality of seedlings Dickson et al. [19] proposed a mathematical formula known as the Dickson Quality Index (DQI) and established the following ranges to interpret the DQI: <0.2 seedlings are of low quality; 0.2-0.5 medium quality; and >0.5 as high quality. With this index, the morphological differences between plants of a sample are better evaluated and it is used to predict the behavior of seedlings in the field. This index is the best parameter to indicate the quality of seedlings based on the distribution of mass and robustness, which for allows determining plants with greater vigor [19, 20]. For a seedling to survive in the definitive field, it must have a DQI greater than 0.5.

Regarding the environment inside the greenhouses, it was established that the main environmental variables to control are temperature, soil humidity, relative humidity and lighting, these parameters must be adjustable for each type of plant according to organic needs [21]. Therefore, this research focused on the evaluation of the influence of controlled environmental variables: temperature, soil humidity, ambient humidity and illuminance inside the *Pinus radiata* seedling greenhouse, on the quality of the seedlings obtained in the greenhouse of the experimental group with respect to the seedlings of the greenhouse of the control group, each one consisted of 300 seedlings.

Materials and Methods

Greenhouse Implementation with Control of Environmental Variables

In the development of the work, various electronic devices have been used to control the different environmental variables. The control algorithm was implemented in the PIC 18F4550 microcontroller, which belongs to the improved range of microcontrollers, with an advanced 16-bit Harvard-type RISC architecture with 8 data bits, it has a set of 77 instructions and 40 pins, it has 13 inputs analog for connection to analog variable sensors with 10-bit resolution [23]. It has a RAM memory of up to 32 Kbytes and 256 bytes of EEPROM memory, on which the control program code for the different environmental variables is stored, with data retention of up to 40 years. The 32-level stack allows the nesting of subroutines to control different variables, it also has USB communication peripherals.

The temperature and relative humidity were measured with the digital sensor DHT11. This device integrates a capacitive humidity sensor and a thermistor to measure the ambient air, and display the digital data on the data pin assigned for his purpose [24]. As for the hardware, it requires a 3-5 V power supply. The communication protocol between the sensor and the PIC 18F4550 microcontroller uses a single terminal. The temperature measurement range covers from 0 to 50ºC, with an accuracy of ±2.0ºC and a resolution of 0.1ºC; Humidity measurement range is from 20% to 90% RH, with accuracy of 5% RH, resolution of 1% RH. The relative humidity measurement values obey Equation (1).

$$\mathrm{RH} = \frac{\rho_w}{\rho_s} * 100\% \quad (1)$$

where RH: relative humidity, ρ_w: density of water vapor, ρ_s: density of water vapor at saturation.

GY-HR10X macromolecule humidity resistance sensor of operating range 0% - 95% RH, used to monitor soil moisture of pine seedlings, this soil moisture sensor is fast response, high sensitivity, stable and reliable response at room temperature of 25ºC [25].

The light intensity sensor used was the LDR (Light Depend Resistor) which is basically a resistor that changes its value when the light intensity changes; covers infrared colors from 890 to 950 nm, red from 660 to 700 nm, green from 560 to 565 nm, resistance for 5 lux is close to 1 MΩ considering open circuit; for high luminance such as 500 lux, the resistance drops to 300 Ω, approaching a short circuit [26].

With the different environmental variable sensors mentioned, the environmental variable controller was implemented in the PIC 18F4550 microcontroller. The variables temperature and relative humidity of the environment were controlled with the algorithm of Fig. 1, programmed in C++ language for microcontrollers [27].

The soil moisture and lighting variables were controlled with the algorithms in Fig. 2, programmed in C++ language for microcontrollers.

These variables were controlled in the different ranges established by connecting the sensors to the inputs of the PIC 18F4550 microcontroller (see Fig. 3), the control program of the different environmental variables was stored in this microcontroller. The value of the environmental variables was monitored from the liquid crystal display (LCD), showing by pairs of variables every 5 s. The setting of the maximum and minimum levels of the different variables subject to control was carried out from the numerical keyboard that includes special keys and a dial tone; the actuators: heater, fan, irrigation valve, sprinkler valve and light lamps, were connected to the microcontroller output by means of 220 Ω resistors, which protected against overloads [28].

The environmental variables control diagram implemented in PIC 18F4550 also sent data of values, obtained by the different sensors and the status of the actuators to a graphical interface developed in LabVIEW [29], which is a graphical engineering

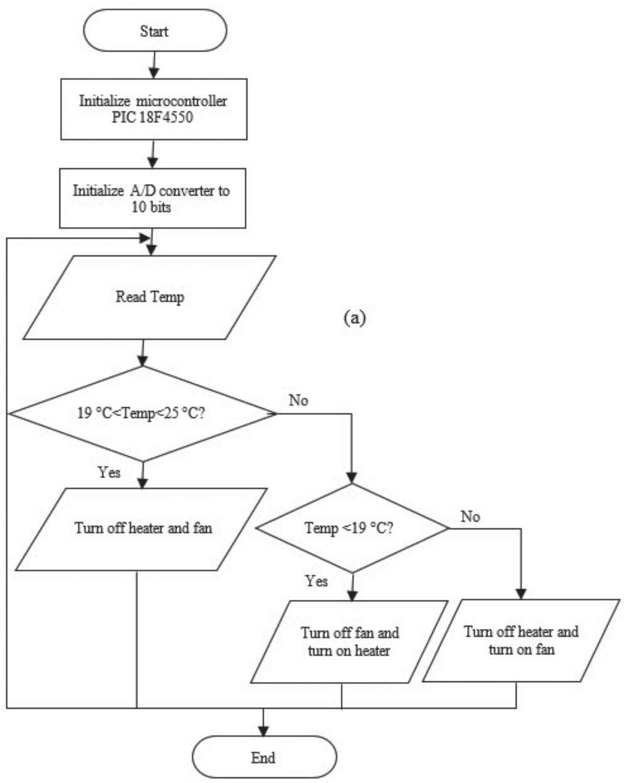

Fig. 1. Diagram of the algorithm for the control of variables: a) temperature and b) relative humidity of the environment; implemented in PIC 18F4550

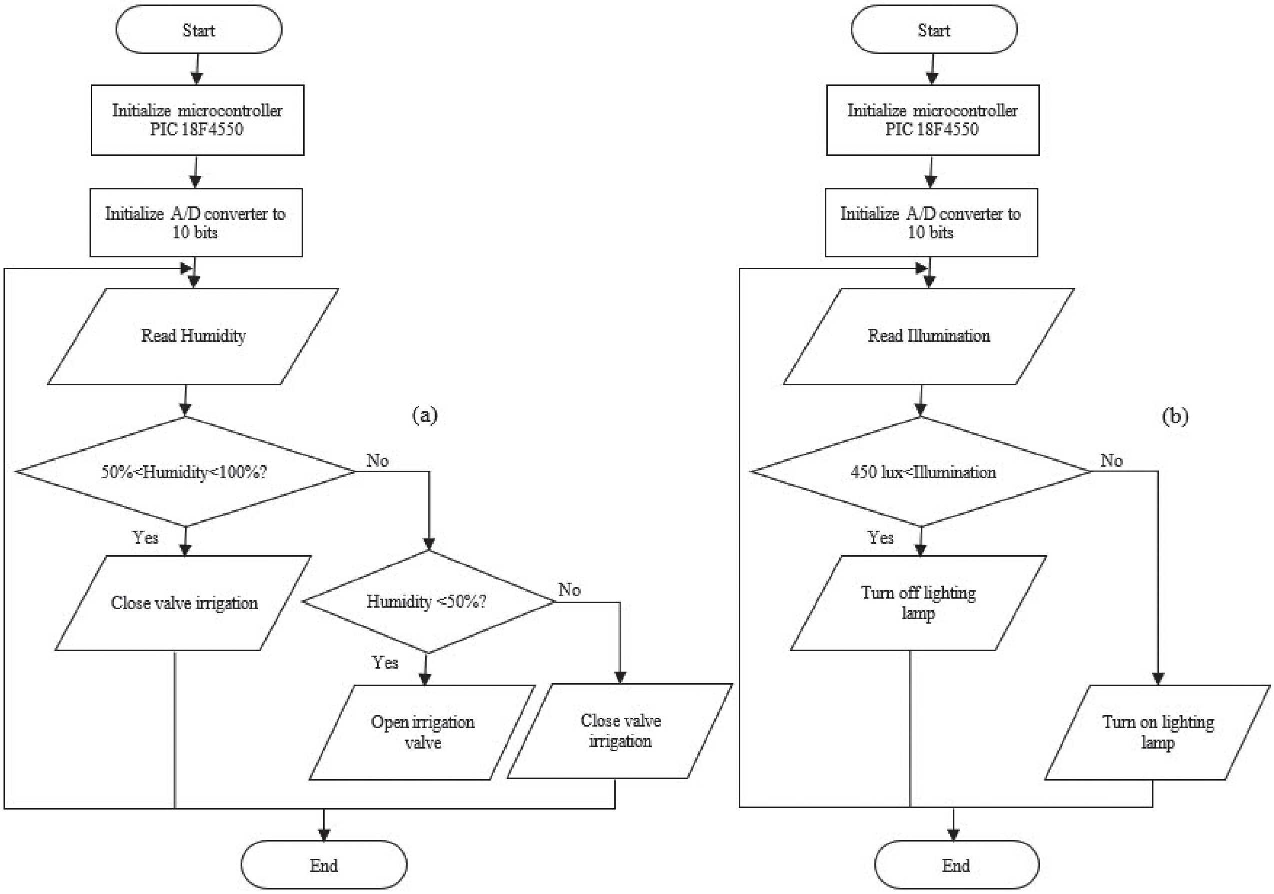

Fig. 2. Diagram of the algorithm for the control of variables: a) soil moisture and b) lighting; implemented in PIC 18F4550.

programming environment used to develop automated research, validation, and production test systems; with which he graphically monitored, on a PC/Laptop screen, the behavior of the different environmental variables and the status of the actuators; this interface being the one shown in Fig. 4.

Methodology Adopted for *Pinus radiata* Development Evaluation

Once the greenhouse has been implemented with controllers for temperature, ambient humidity, soil humidity and light intensity (Fig. 4); 300 *Pinus radiata* seedlings with approximate heights of 5 cm contained in bags with peat and sand in the proportion of 6:1, which were previously germinated in a nursery for one month, were transplanted into this greenhouse, being considered the experimental group. In the same way, another 300 seedlings, with similar characteristics germinated in the same nursery, were transplanted to another adjacent greenhouse that does not include automatic control of environmental variables, the latter being considered as a control group.

After 6 months, 10 seedlings from the experimental group and 10 seedlings from the control group were randomly selected, which were dried in an oven at 80ºC for 72 hours. Then, the evaluation of the morphological variable Dickson's quality index presented in Equation (2) was carried out, which allows establishing the adaptation capacity of the plant when it is transferred to the definitive field [30].

$$\mathrm{DQI} = \frac{\text{Total dry weight (g)}}{\frac{\text{Dry weight air part (g)}}{\text{Dry weight root (g)}} + \frac{\text{Height } (\mathbf{cm})}{\text{Diameter (mm)}}} \quad (2)$$

Results and Discussion

Once the environmental variables controller was implemented, various tests were carried out for different reference points (setpoint) of each variable to be controlled, obtaining as a result different data for 24 hours during 10 days of testing.

Table 1 shows the values of the environmental variables controlled inside the greenhouse for variables in different pre-established ranges: 19ºC≤Temp≤ 25ºC, 50%≤Humidity≤100%, 70%≤RH≤90% and Illumination≥450 lux.

The controlled temperature, based on the algorithms implemented in the PIC 18F4550 microcontroller, has a minimum value of 19ºC and a maximum value of 24.5ºC, with an average of 21.54ºC, which is within the preset control range for seedlings of *Pinus radiata*.

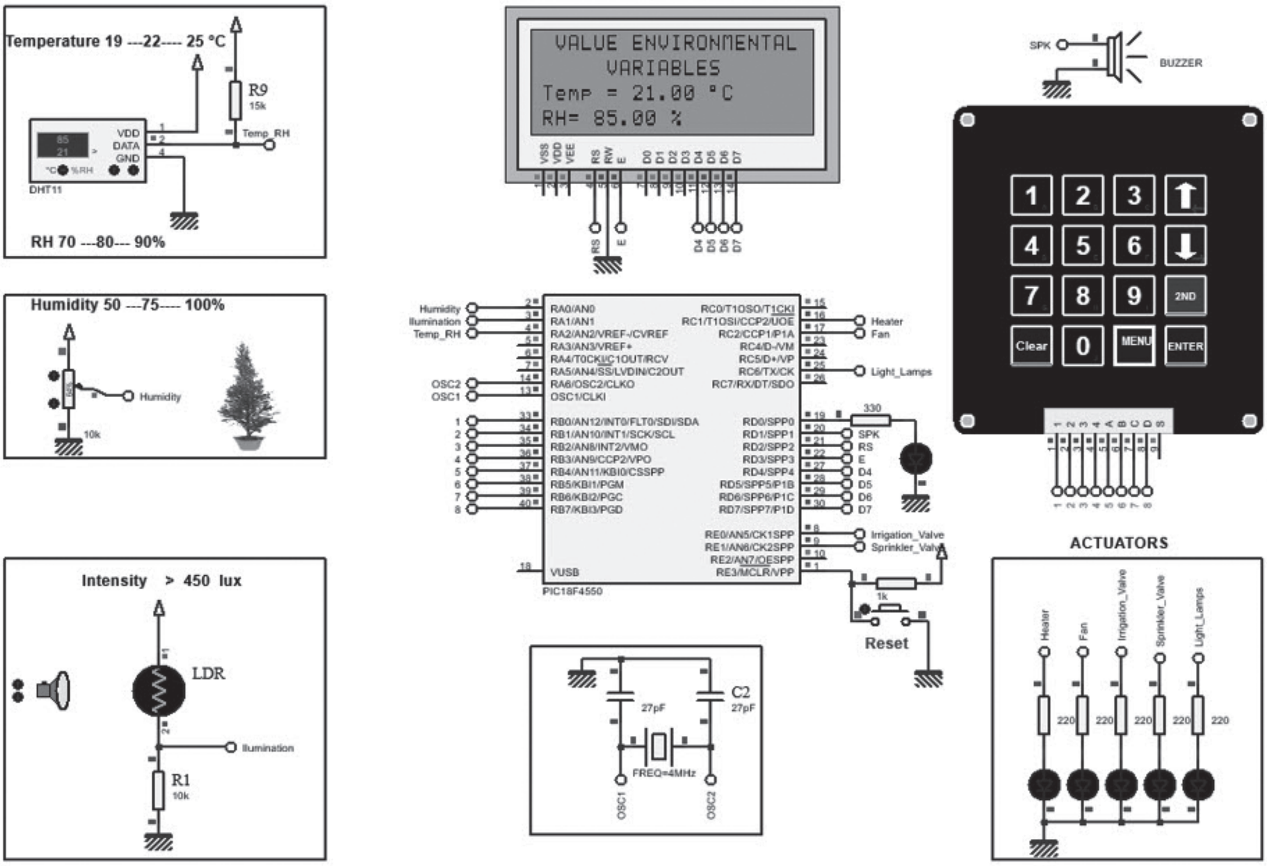

Fig. 3. Diagram of the controller of environmental variables implemented in PIC 18F4550.

Likewise, soil moisture has a minimum value of 51.10% and at the time of irrigation a maximum of 99% was achieved, the average is 81.81%. The minimum ambient humidity is 71.5% and the maximum value is 84.90%, with an average of 78.36%. The intensity of the minimum illumination was 440.30 lux and the maximum under control was 459 lux, with an average of 451.62 lux, while the illumination from the Sun between the hours of 8:00 am and 4:00 pm approximately, was not observed. Controlled [21].

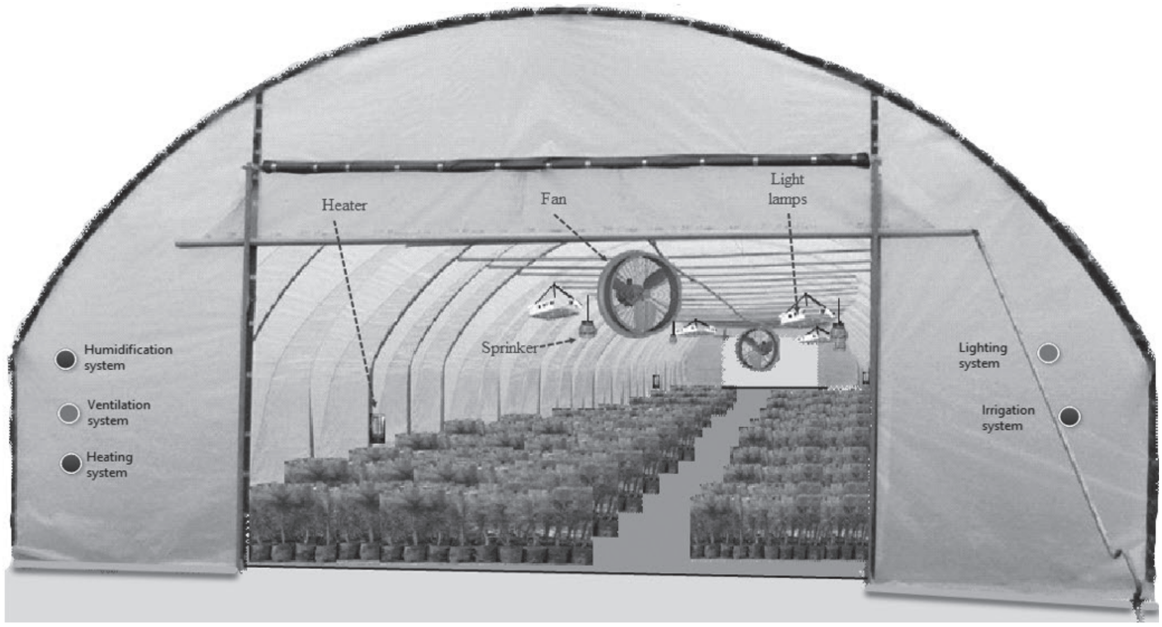

Fig. 4. Graphic interface for monitoring environmental variables and actuator status implemented in LabView.

Table 1. Value of the environmental variables controlled inside the greenhouse.

Time	Temperature (ºC)	Humidity (%)	RH (%)	Illumination (lux)
08:00	22.50	93.00	73.40	14410.59
09:00	20.30	78.80	85.60	18379.63
10:00	19.30	52.40	87.10	16845.37
11:00	19.50	90.80	84.80	31055.05
12:00	19.80	91.50	77.60	26350.02
13:00	19.60	70.40	79.20	31089.19
14:00	21.70	68.60	76.90	31592.02
15:00	21.80	89.60	82.40	11298.66
16:00	24.10	59.20	81.10	11459.19
17:00	19.30	70.20	71.10	8171.01
18:00	23.40	92.90	76.00	6288.49
19:00	23.30	67.80	78.40	442.80
20:00	23.20	52.90	86.60	450.90
21:00	21.80	58.20	77.30	449.80
22:00	20.30	66.40	85.20	451.50
23:00	24.50	84.40	79.30	452.20
00:00	23.80	65.90	84.20	440.30
01:00	21.00	84.30	79.70	458.30
02:00	24.50	74.70	70.50	454.80
03:00	21.70	92.00	74.00	458.20
04:00	21.10	79.50	74.00	453.50
05:00	22.30	77.60	79.50	458.40
06:00	19.20	51.10	85.20	441.40
07:00	19.00	90.00	74.60	459.00
Average	21.54	75.09	79.32	451.62

Table 2. Measured parameters of the *Pinus radiata* seedlings of the control group.

Seedling	Transplant height (cm)	Height (cm)	Diameter (mm)	Dry weight air part (g)	Dry root weight (g)	Total dry weight (g)	Dickson Quality Index (DQI)
S-101	4.80	15.80	2.40	2.80	1.38	4.18	0.485
S-102	4.82	15.90	2.20	2.70	1.20	3.90	0.412
S-103	4.78	15.70	2.30	2.60	1.22	3.82	0.426
S-104	4.79	15.70	2.10	2.70	1.25	3.95	0.410
S-105	4.71	15.80	2.00	2.50	1.33	3.83	0.392
S-106	4.80	15.70	2.30	2.60	1.44	4.04	0.468
S-107	4.75	15.80	2.20	2.80	1.46	4.26	0.468
S-108	4.80	15.80	2.10	2.50	1.23	3.73	0.390
S-109	4.90	15.90	2.20	2.60	1.25	3.85	0.414
S-110	5.00	16.00	2.30	2.70	1.42	4.12	0.465
Average	4.82	15.81	2.21	2.65	1.32	3.97	0.433

Table 3. Measured parameters of the *Pinus radiata* seedlings of the experimental group.

Seedling	Transplant height (cm)	Height (cm)	Diameter (mm)	Dry weight air part (g)	Dry root weight (g)	Total dry weight (g)	Dickson Quality Index (DQI)
S-201	4.80	29.20	3.40	3.85	1.97	5.82	0.552
S-202	4.80	29.50	3.20	3.75	1.88	5.63	0.502
S-203	4.90	29.10	3.20	3.65	1.88	5.53	0.501
S-204	4.90	29.40	3.20	3.50	1.91	5.41	0.491
S-205	4.80	29.30	3.40	3.25	1.93	5.18	0.503
S-206	4.78	29.70	3.60	3.90	1.95	5.85	0.571
S-207	4.70	29.60	3.50	3.88	1.94	5.82	0.557
S-208	4.80	29.30	3.60	3.55	1.76	5.33	0.525
S-209	4.80	29.40	3.30	3.51	1.82	5.33	0.492
S-210	4.90	29.50	3.20	3.50	1.84	5.34	0.480
Average	4.82	29.40	3.36	3.63	1.89	5.52	0.517

Pine radiata Development Evaluation

The Pinus radiata seedlings with an average initial height of 4.82 cm that were part of the control group (S-101 to S-110) transplanted to the tunnel type greenhouse with uncontrolled environmental variables, being the processes of irrigation and ventilation in a traditional way; after 06 months the DQI was calculated, prior to this calculation the mass was dried in an oven at 80ºC for 72 hours. Table 2 presents the results of the measurement of the different parameters of Pinus radiata seedlings, where the minimum DQI is 0.39, maximum DQI is 0.485, and average DQI is 0.433, indicating that the seedlings are of medium quality [19, 20].

The *Pinus radiata* seedlings from the experimental group (S-201 to S-210), transplanted to the tunnel-type greenhouse with controlled environmental variables, whose average height was also 4.82 cm and whose DQI was calculated after 06 months, drying was carried out in an oven at 80ºC for 72 hours. Table 3 presents the results of the measurement of the different parameters of *Pinus radiata*, where the minimum DQI is 0.48, maximum DQI is 0.571, and average DQI is 0.517, which indicates that the seedlings are of high quality having the greatest possibility of survival in the definitive field, as established Dickson et al. in the work "Quality appraisal of white spruce and white pine seedling stock in nurseries" [19].

The normalized variances of the DQI between both samples of *Pinus radiata* seedlings were tested with Fisher's bilateral F test, finding that the ratio of the variances is around 1, indicating that the variances of both samples are equal. Fig. 5 shows the F(obs) which

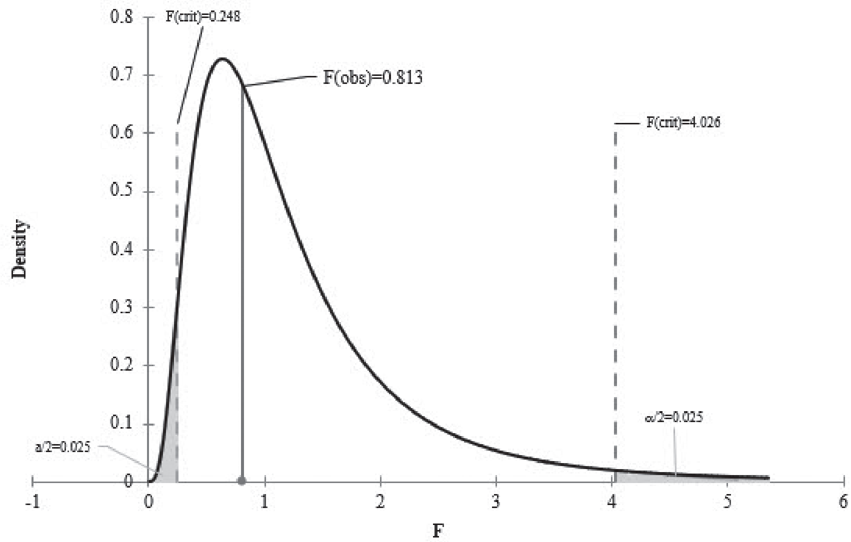

Fig. 5. Two-tailed Fisher's F test of the DQI of the samples of *Pinus radiata* seedlings from the control and experimental groups.

is located within the acceptance zone of the null hypothesis.

On the other hand, when analyzing the significant difference of the normalized DQI between the control group and the experimental group, a significant difference of plus 5% was found; the result of the two-tailed t-test for independent samples yielded a p-value (Two-tailed) = 0.002, which is less than the significance level alpha = 0.05.

Conclusions

The environmental variables controller implemented in a PIC 18F4550 microcontroller, tested its operation for 24 hours for 10 days. The temperature was maintained within the range 19ºC-25ºC, with the minimum being 19ºC, maximum 24ºC. Relative humidity was maintained within the range 70% -90%, with the minimum being 71 % and the maximum 90%. Likewise, soil humidity remained within the range 50%-100%, with a minimum of 50.5% and a maximum of 100%. Finally, the illumination is greater than 450 lux, with a minimum of 451.70 lux generated by the lamps and a maximum of 49950.40 lux generated by daylight. Therefore, the controller generated a favorable environment for the development of the Pinus radiata seedlings that constituted the experimental group.

It was found that the Dickson quality index of Pinus radiata seedlings from the control group averaged 0.433 classified as medium quality and Pinus radiata seedlings from the experimental group had an average DQI of 0.571 classified as high quality for survival in the final field. The normalized Dickson quality index found for the Pinus radiata seedlings of the control and experimental groups was evaluated, obtaining a significant difference of more than 5% with the t-test for two-tailed independent samples yielding a p-value (Two-tailed) = 0.002, which is less than the significance level alpha = 0.05.

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Conflict of Interest

The authors declare no conflict of interest.

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