POTENTIAL OF NATIVE MAIZE IN THE PRODUCTION OF HYDROPONIC GREEN FODDER UNDER TROPICAL CONDITIONS †

[POTENCIAL DEL MAÍZ NATIVO EN LA PRODUCCIÓN DE FORRAJE VERDE HIDROPÓNICO BAJO CONDICIONES TROPICALES]

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SUMMARY

Background: Hydroponic Green Fodder (HGF) is a technology that allows the efficient production of fresh forage with a high protein content. **Objective:** To analyze the bromatological and productive variables of HGF with four native maize varieties located in the southern region of the state of Veracruz, Mexico. **Methodology:** Bromatological and productive parameters of four varieties of native corn (V1= Soteapan white, V2 = Tulín white, V3 = Mecayapan yellow, V4 = Cosoleacaque white) were analyzed in Acayucan, Veracruz. The productive variables evaluated were height, biomass and potential yield (Py)], while the bromatological were: Dry Matter (DM), Ash (A), Crude Protein (CP), Crude Fiber (CF) and Ethereal Extract (EE), the relationship between the dry weight of the seed (ws) and Py was also analyzed. The experimental design was completely randomized with three replications, using 200 g^{-1} of seed of each variety placed in germination trays of 30 cm^{-2}, using a nebulization system of 6.6 to 7.2 L h^{-1} and an irrigation frequency of two minutes every four hours. The variables were analyzed with the Tukey test using SAS University Edition software and Pearson's linear correlation was used to determine the relationship between ws and Py. **Results:** V1 was the best variety in height (34.3 cm^{-1}), Py (21.5 kg m^{-2}) and PC (22.13%), with 29% more roots and correlating with heavier seeds. **Implications:** The study was carried out with a nebulization system with a higher frequency of irrigation, since it was carried out in the months of May-June, with temperatures above the average. Therefore, it is necessary to adjust the irrigation time according to the environmental conditions. **Conclusion:** It is concluded that the native varieties V1 and V2 have a high potential for the production of HGF.
Keywords: nutritional quality; productive alternative; sustainability; agricultural development.

RESUMEN

Antecedentes: El Forraje Verde Hidropónico (FVH) es una tecnología que permite la producción eficiente de forraje fresco con alto contenido de proteína. **Objetivo:** Analizar las variables bromatológicas y productivas del FVH con cuatro variedades nativas de maíz ubicadas en la región sur del estado de Veracruz, México. **Metodología:** Se analizaron parámetros bromatológicos y productivos de cuatro variedades de maíz nativo (V1=blanco Soteapan, V2= blanco Tulín, V3=amarillo Mecayapan, V4= blanco Cosoleacaque) en Acayucan, Veracruz. Las variables productivas evaluadas fueron: altura, biomasa y rendimiento potencial (Rp), mientras que las bromatológicas fueron Materia Seca (MS), ceniza (C), Proteína Cruda (PC), Fibra Cruda (FC) y Extracto Etéreo (EE), también se analizó la relación entre el peso seco de la semilla (ps) y el rendimiento potencial (Rp). El diseño experimental fue completamente al azar con tres repeticiones, utilizando 200 g^{-1} de semilla de cada variedad colocadas en charolas de germinación de 30 cm^{-2}, usando un sistema de nebulización de 6.6 a 7.2 L h^{-1} y una frecuencia de riego de dos minutos cada cuatro horas. Las variables fueron analizadas con la prueba de Tukey mediante el software SAS University Edition y se utilizó la correlación lineal de Pearson para determinar la relación entre ps y Rp. **Resultados:** V1 fue la mejor variedad en altura (34.3 cm^{-1}), Rp (21.5 kg m^{-2}) y PC (22.13 %), existiendo 29% más raíces y correlacionando con semillas más pesadas (R^2= 0.92). **Implicaciones:** El estudio se llevó a cabo con un sistema de nebulización con una mayor frecuencia de riego, debido a que realizó en los meses de mayo-junio, con temperaturas superiores a la media. Por lo anterior, se siguiere ajustar el tiempo de riego de acuerdo con las condiciones ambientales. **Conclusiones:** Se concluye que las variedades nativas V1 y V2 tienen un alto potencial para la producción de FVH.
Palabras clave: Calidad nutrimental; alternativa productiva; sustentabilidad; desarrollo agropecuario.

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INTRODUCTION

Hydroponic Green Fodder (HGF) is a technology that allows the production of fresh forage of high digestibility and high nutritional quality (11–14% protein), very suitable for animal feeding with 18% dry matter (DM), which is obtained from germination and the early growth of grass and legume seedlings, harvested in a time of seven to twelve days, where only 1.55 - 3.0 L of water kg-1 of HGF is required (Naik *et al.*, 2015), which has been widely used in countries like Arabia and India (Al-Karaki and Al-Hashimi, 2012; Jemimah *et al*., 2018). While in Mexico, its production is concentrated in arid, semi-arid and temperate zones corresponding to the north and center of the country, where some varieties of corn, barley, oats and wheat are used (Cerrillo *et al*., 2012; Pérez *et al*., 2012; Sánchez *et al*., 2013), wasting the potential of tropical areas and their plant genetic resources.

Maize has been reported as the most efficient species in the use of water and yield (Bamikole *et al.*, 2020). In this regard, the ideal period for HGF is ten days after germination, because in this phenological state, the plant has a higher protein and energy content for ruminant nutrition (Herrera-Torres *et al.*, 2010), finding differences between the varieties of yellow and white corn with a yield of 6.92 y 6.74 kg m^{-2}, respectively (Lamnganbi and Surve, 2017); however, this can be attributed to parameters such as shoot, root and seed weight (Ningoji *et al.*, 2020), which depend on the genetic characteristics of the seed and the edaphoclimatic conditions, such is the case of yellow maize that have been selected to produce FVH, whose total yield corresponds 66.67% to the root and 33.33% to the shoots (Jemimah *et al.*, 2020). White corn varieties with high potential have also been selected, such as the "Morocho Blanco" cultivar, obtaining yields of up to 10.34 kg m^{-2} (González *et al.*, 2015). These fodder can contain on average 20.01% crude protein; 18.95% crude fiber; 4.5% ash; 7.44% ethereal extract and 88.6% dry matter digestibility (Soto-Bravo and Ramírez-Víquez, 2018), parameters that make these sprouts of high nutritional quality for animal feed (López-Aguilar *et al.*, 2009).

The main productive advantage of the HGF is the lower loss of water by surface runoff, infiltration and evapotranspiration (8 L of water is required to produce a kg^{-1} of dry matter of HGF, or 521 kg of humid biomass m^{-3} of water (Al-Karaki and Al-Hashimi, 2012). Other advantages are: the shortest time in production, because the complete cycle is 10 to 14 days; the availability of fresh forage, which can reach 20 to 30 cm^{-1} in height (Naik *et al.*, 2014) although the biggest disadvantage is that it depends a lot on the efficiency of the seed to produce quality forage, since 90% of the viability of the HGF technique corresponds to the correct selection of the seed (Nonigopal, 2019). Therefore, the selection of a seed that is easily available, agronomically productive and adaptable to the agroclimatic conditions of the region is decisive. The aim of this study was to analyze the bromatological and productive variables of HGF with four native maize varieties located in the southern region of the state of Veracruz, Mexico.

MATERIALS AND METHODS

Study Area

The native maize varieties were collected in the municipalities of Soteapan and Mecayapan, located in the Sierra of Santa Marta (Figure 1), where these varieties have been reported (Tello and Jönsson, 2019) and whose edaphoclimatic conditions are: altitude of 994 m, rainfall of 1182 mm, average annual temperature of 24.9 ºC and Chromic and Acrisol soils (Cram *et al.*, 2015). On the other hand, in Cosoleacaque the climate is hot and humid with a rainfall of 1900 to 2600 mm, it presents an annual average temperature of 25.8˚C with maximum temperatures of 42˚C to 44˚C (May and June), it also registers abundant rains in summer and early fall. The area is characterized by floodplain coastal mostly with Gleysol soil type, followed by Luvisol in alluvial plains with hills (INEGI, 2009).

The study was carried out in the Experimental Module of Hydroponic Green Fodder of the Faculty of Engineering in Agricultural Production Systems, belonging to the Universidad Veracruzana in Acayucan, Veracruz, Mexico (Figure 1), located at coordinates 18°00'14.0"N. and 94°55'45.1"W, at an altitude of 100 m with an annual mean temperature of 24-28 ºC and with a precipitation of 1400 - 1600 mm, characterized by a warm subhumid climate with rains in summer, hills and Vertisol soils (Pérez-Prieto *et al.*, 2018). The HGF module has a surface area of 12 m^{-2}, has a mist irrigation system and eight vertical racks of 2.20 m^{-1} in height, with a capacity of four cultivation platforms per rack.

Bioassays

The study was carried out in two phases, in the first the bioassays were developed in controlled environments with seedlings of corn, for this, four varieties of native maize from the southeast of Veracruz were selected, the indicators in this selection were: 1) seeds that had 90% germination in the laboratory, 2) varieties easily accessible by producers, and 3) varieties harvested in the current cycle. With this, three native varieties from the upper Michapan basin (V1, Soteapan white maize; V2, Tulín white maize; V3, Mecayapan yellow maize) and a variety from the lower basin (V4, Cosoleacaque white maize) were selected. A completely randomized design was established with three replications, where

200 g^{-1} of seed were weighed for each variety and these were placed in germination trays of 30 cm^{-2}, using the standardized methodology for HGF that included selection and weighing of the seed with a sowing density of 6.6 kg m^{-2}, considered as medium-low (Assefa *et al.*, 2020). Pre-washing and washing were performed with 1% sodium hypochlorite, with a soak in a water solution with 10% calcium hydroxide for 20 h^{-1}. Germination in the dark phase lasted two days, while fertigation was carried out from the fourth day with Hydro Environment®, and the harvest lasted until the tenth day (Vargas-Rodríguez, 2008). Irrigation was carried out with a nebulization system with a water consumption of 6.6 to 7.2 L h^{-1} and with a frequency of two minutes of irrigation, every four hours, while the water-maintained parameters of pH of 8.21 and electrical conductivity of 0.47 dS m^{-1}.

Variables

Productive variables: At the beginning of the experiment, three replicates of 40 seeds were weighed to estimate the dry weight of the seed (***ws***), by variety. After sowing, the root and aerial height (leaves) of the mat was measured every two days, while the wet biomass was measured up to 10 days after sowing. The potential yield (***Py***) was estimated by the area (***Ab***) and root (***Rb***) biomass with 90% humidity produced in one square meter, expressed with the following formula:

$$i = 1, 2, 3 \ldots maize\ seed\ variety$$

$$\text{Py} = \sum_{i=1}^{n} [(Ab + Rb)*1000]/\text{A}$$

Where:

Pyx= Potential yield of maize under Hydroponic Green Fodder.

Ab= Aerial biomass (leaves) with 90% humidity expressed in grams (g^{-1}).

Rb= Root biomass (roots) with 90% humidity expressed in grams (g^{-1}).

A= Hydroponic tray area expressed in centimeters (cm^{-2}).

n= Number of replicas.

i= Variety.

Bromatological variables: Ten days after sowing, the following proximal parameters were determined: dry matter (DM) by the drying method in a 65ºC forced ventilation oven for 72 hours at constant weight (Posada *et al.*, 2007), Ethereal Extract (EE) by extract soluble in ether on the dry sample in the Soxhlet extractor, Crude Fiber (CF) was determined by the method of fiber fractions or Van Soest, Crude Protein (CP) by the standard micro Kjeldahl method and the Ash by combustion in a muffle for 3h at 600 ºC (Helvich, 1990; Mamani and Cotacallapa, 2018). The area and root biomass were analyzed separately in order to analyze their nutritional contribution.

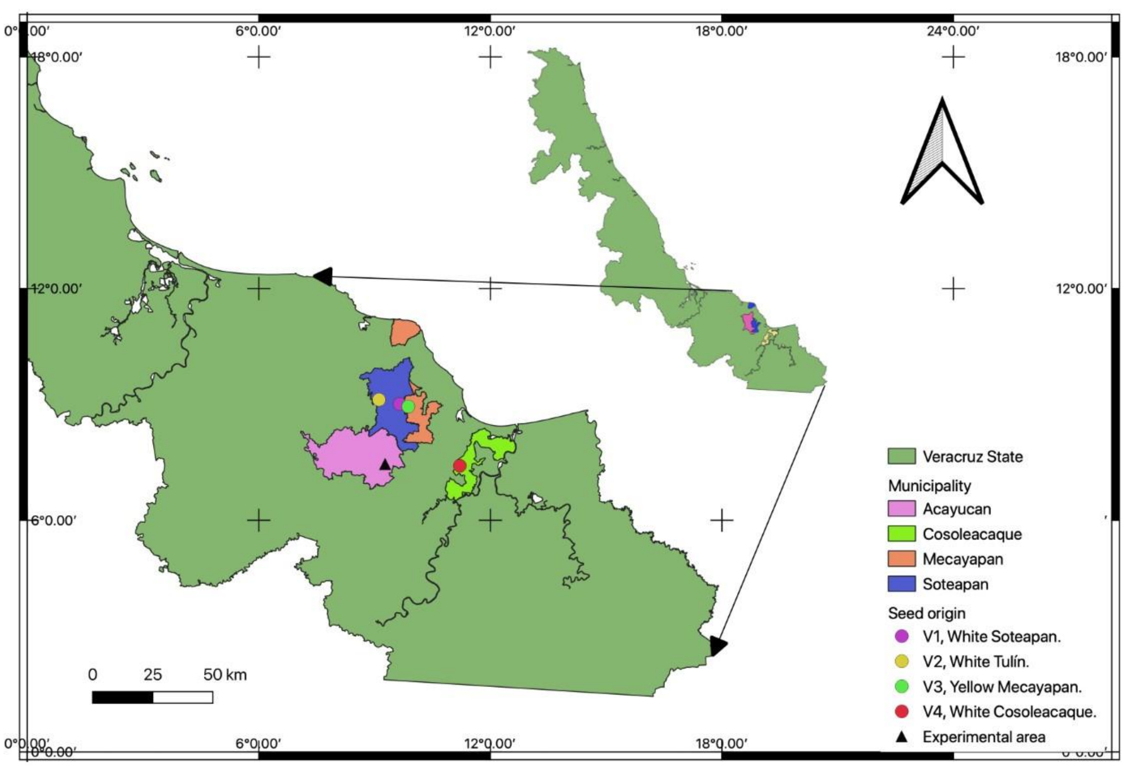

Figure 1. Location of the maize varieties and the experimental zone.

Statistical analysis

The results were analyzed with SAS (2018) University Edition software, 2.8.1 9.4 M6 Version, using the PROC GLM procedure and the Tukey test (a = 0.05). In order to understand the relationship between the potential yield of the HGF and the size of the seed, a linear Pearson correlation was made between the variables Py, dry weight of the seed (ws) and potential yield (Py) with the software JASP Team (2020) version 0.14.1.

RESULTS

Significant differences ($p < 0.05$) were found in the growth (Figure 2), and biomass accumulation of the HGF between the four native varieties, being the V1 with the highest height (34.3 cm^{-1}) and Rp (21.5 kg m^{-2}), followed by V2 with 18.7 kg m^{-2}, although with a lower height (27.75 cm^{-1}). This corresponded from 7% to 16.7% of the root zone in V3 and V4, while in V1 and V2 it corresponded between 29% and 32% of the total Py, significantly correlated the root height of the mat (R^2= 0.784) with Py (Figure 3A).

The highest Py of the HGF was significantly correlated with ws (R^2=0.703), this moderate association allows to identify a characteristic to consider, where seeds with greater weight could present higher yield of the potential HGF, as long as it has a percentage germination greater than or equal to 90%. In this study, native maize with seeds of 0.47g and 0.38 g showed to have between 27.2% and 36.1% higher yield, respectively, than varieties with lower dry weight (Figure 3B).

The bromatological variables also reported significant differences ($p < 0.05$), being maize from Mecayapan (V3) obtaining the best nutritional quality (higher protein 26.19% and CF 38.38% in leaves) followed by V1 and V2, while the least suitable maize for HGF was V4 from Cosoleacaque with only 17.90% protein in leaves and 14.55% in roots (Table 1).

DISCUSSION

The height of the HGF ranged between 34.3 cm^{-1} (V1) and 28.5 cm^{-1} (V2), being higher than the following studies: 22.2 cm^{-1} at 13 days (Zagal-Tranquilino *et al.*, 2016), 30.45 cm^{-1} at 14 days (Preciado *et al.*, 2014), 13.7 cm^{-1} y 30.45 cm^{-1} 15 days after sowing (Maldonado *et al.*, 2013). In this study, the harvest was carried out at 10 days, which indicates the great capacity of these native maize from the Sierra de Santa Marta to produce HGF. This may be due to the ability of these varieties to produce a mat with a high content of roots, since these correspond between 29 and 32% of the total yield. In this regard, studies suggest that root elongation can increase by 5 cm^{-1} from the second to the fourth day, but it doubles its length from the fourth day to the sixth day (10.3 cm^{-1}) and stabilizes at 5.4 cm^{-1} from the sixth to the eighth day (Rajesh *et al.*, 2018)

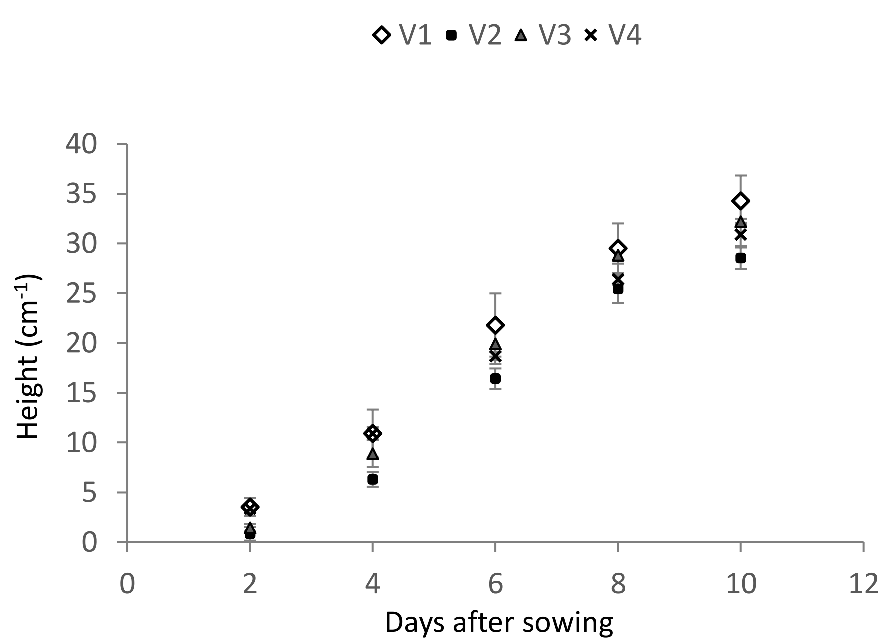

Figure 2. Hydroponic Green Fodder height with four varieties of native maize: V1 = white Soteapan, V2 = white Tulín, V3 = yellow Mecayapan, V4 = white Cosoleacaque.

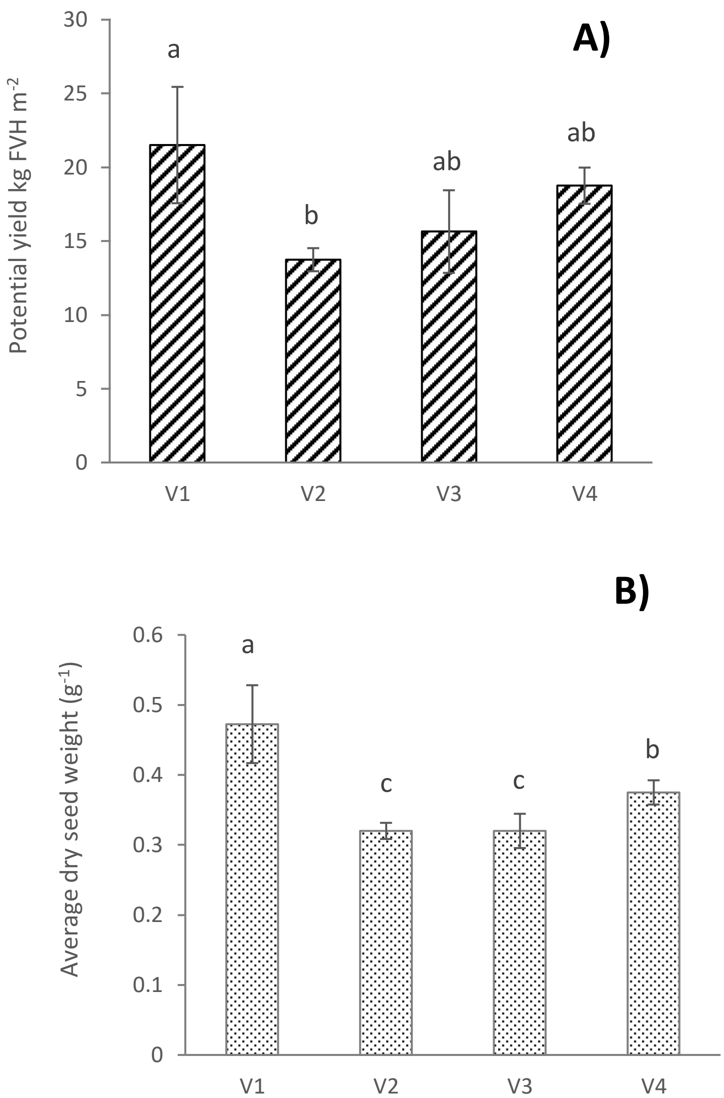

Figure 3. Section A) Potential yield of the Hydroponic Green Fodder with 90% humidity and B) weight of the seed of four varieties of native maize: V1 = white Soteapan, V2 = white Tulín, V3 = yellow Mecayapan, V4 = white Cosoleacaque, to produce one kilogram of Hydroponic Green Fodder with 0% humidity. The different letters a, b, c indicates significant differences (P≤0.05).

The highest Py was reported in V1 (21.5 kg HGF m^{-2}), followed by V4 (18.7 kg HGF m^{-2}), V3 (15.6 kg HGF m^{-2}) and V4 with 13.7 kg HGF m^{-2}, being V1 higher than those reported with techniques such as mineral nutrition high in N, where productions of 15.28 kg FVH m^{-2} (Ramírez and Soto, 2017) and 19.950 kg HGF m^{-2} (Maldonado *et al.*, 2013), while with the use of organic compounds such as vermicompost, 19.71 kg HGF m^{-2} can be achieved (Pérez *et al.*, 2012). Although, varieties with yields of up to 27.14 kg HGF m^{-2} have been found, these data have been taken 17 days after sowing (García *et al.*, 2017). However, the highest concentrations of lysine are found between days 11 (Soto-Bravo and Ramírez-Víquez, 2018), another aspect to consider at harvest time is the metabolizable energy and tryptophan content, since this type of forage is for animal feed. In this regard, it has been found that metabolizable energy is higher between days 10 and 11, with an estimated value of 2,877 Mcal kg^{-1} HGF (Trevizan and Challapa, 2020), for that reason, in this study it was harvested at 10 days.

Table 1. Bromatological parameters of root and aerial Hydroponic Green Fodder (leaves) with four varieties of native maize: V1 = white Soteapan, V2 = white Tulín, V3 = yellow Mecayapan, V4 = white Cosoleacaque.

	Dry matter †	Ash ‡	Ethereal Extract	Crude protein	Crude fiber
	- - - - - - - - - - - - - - - -	- - - - - - - - - - - - - - - - %	- - - - - - - - - - - - - - - -		
Aerial					
V1	19.61 a	5.79 b	5.38 ab	22.13 ab	38.68 a
V2	29.30 a	10.02 a	4.26 b	22.86 ab	38.38 a
V3	28.74 a	9.16 a	8.87 a	26.19 a	22.75 c
V4	16.82 a	7.77 ab	8.80 a	17.90 b	26.28 b
MSE	6.06	0.90	1.49	3.06	0.48
P=	0.1164	0.0022	0.0103	0.0060	<0.0001
Root					
V1	10.27a	3.05 a	3.47 b	13.12 a	13.84 a
V2	9.95 a	1.76 b	7.02 ab	14.02 a	8.17 c
V3	8.75 a	2.19 b	5.29 ab	16.15 a	11.10 b
V4	9.20 a	2.45 ab	9.26 a	14.55 a	13.84 a
MSE	1.07	0.28	1.75	1.99	0.53
P=	0.3544	0.0034	0.0198	0.3617	<0.0001

† Original means; data transformed according to $\sqrt{X}$. ‡ Means with the same letter within each column do not differ statistically (Tukey, $P \leq 0.05$). The different letters a, b, c indicates significant differences ($P \leq 0.05$).

Another important factor in the yield is the vigor of the seed, which is observed during the establishment of the seedling and its behavior under environmental conditions such as temperature and water availability (Finch-Savage and Bassel, 2015), although in hydroponic fodder humidity can be controlled. Another factor to consider in HGF is the weight of the seed, since during the first stages of germination, it depends on the reserves of the seed (Martinelli and Carvalho, 1999). In this regard, investigations carried out in conditions of controlled humidity indicate that larger seeds produced seedlings with better vegetative growth than those from small seeds (Laynez-Garsaball *et al.*, 2007), which would explain the results of this experiment. This may be due to the difference in growth rate, which is related to the rate of conversion of starch stored in the seed into a simple sugar, which produces energy and emits carbon dioxide and water (Bakshi *et al.*, 2017).

The results show that the wet biomass production of the four varieties was higher in concentration of crude protein (7.92%) and dry matter (11%) reported in Costa Rica (Vargas-Rodríguez, 2008); even V1, V2 and V3 exceed 19% of PC, found in various studies that report from 16.75 to 19% (Bedolla-Torres *et al.*, 2015). The CF data was higher than 18.95% and ashes 7.4% (Soto-Bravo and Ramírez-Víquez, 2018), while the EE values in V1 and V2 were higher than the 24% of FC reported in Mexico (Espinosa, 2019). In this regard, Bakshi *et al*, (2017) explain that the conversion of starch stored in the seed by soaking activates the enzymes in the endosperm to a simple sugar, producing energy and emitting carbon dioxide and water, this process leads to loss of DM with a change from starch to fiber and pectin in the roots and green shoots.

CONCLUSION

V1 was the best variety in height (34.3 cm^{-1}), yield (21.5 kg m^{-2}) and CP (22.13%), due to the fact that they produced 29% more roots (R^2= 0.784), it is concluded that this research allowed to select the best native maize (V1) for the production of HGF under the technical conditions of the present study.

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Conflict of interest statement. The group of authors declares that there are no conflicts of interest in this research.

Compliance of ethical standards. Nothing to declare/does not apply.

Data availability. The data is available with <Dinora Vázquez Luna, divazquez@uv.mx> upon reasonable request.

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