Article

Prickly pear glochids for commercial production of oyster mushroom

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Abstract

Prickly pear glochids were evaluated as an improvement component of substrate for the commercial production of *Pleurotus* sp. carpophores through the productivity parameters of earliness (E), biological efficiency (%, BE), yield (%, Y), production rate (%, PR) and economic indicators. Whole (EE) or ground (EM) glochids were mixed with oat straw (RA) in proportions of 20%, 30% and 40%, in addition to the traditional control (100% oat straw) in a completely randomized design with six repetitions per treatment. The harvest began 30 days after sowing the mycelium, at the time when the gill of the carpophores had thinned edges. The response variables were subjected to an analysis of variance and comparison of means with a confidence level of 95%. The addition of ground glochids significantly decreased the number of days (E) needed for colonization with respect to the control. The best treatments for commercial production were: 60RA-40EM with yield (Y) percentage of 38.3 ±10.9, BE of 132.3 ±37.5% and PR of 3 ±0.9% and treatment 70RA-30EM with Y of 38.2 ±9.4%, BE of 124.7 ±30.7% and PR of 3 ±0.6%. Substrates with whole glochids also met the criterion of productive quality, with Ys greater than 10% and BEs greater than 100%. The use of 40% of EM represented savings in straw consumption with an increase in annual net profit of $3 353.53, compared to traditional production management. The by-product of the waste from the processing of prickly pear is an economically feasible option for the commercial production of *Pleurotus* sp.

Keywords: *Pleurotus* sp., carpophores, production parameters, substrates.

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Introduction

The prickly pear of *Opuntia albicarpa* Scheinvar is used in obtaining a wide variety of products. Within the processing of prickly pear, a large amount of glochids is produced, according to Ulloa-Leitón *et al*. (2021), for each tonne of clean prickly pear, 65 kg of this material is generated, which is of no use for producers; given its difficult handling, its resistance to natural degradation, even burning, it is discarded in plastic bags in landfills, generating a problem of environmental pollution. Studies of this by-product indicate that its resistance to microbial decomposition is due to its high content of cellulose (41.14%), hemicellulose (41.21%) and lignin (5.27%) in crystallized state (Ulloa-Leitón *et al*., 2021).

Some authors mention that this type of structures can be weakened by the action of fungi such as *Pleurotus ostreatus*, widely known for its ability to convert lignocellulosic agricultural waste into foods (Nieto and Chegwin, 2010). The production of *Pleurotus ostreatus* (oyster mushrooms) is based on using the lignocellulosic agricultural residues as a substrate to produce food with high protein content depending on the species of oyster mushroom and the characteristics of the substrate (Bermúdez *et al*., 2007; Jeznabadi *et al*., 2016; Valencia *et al*., 2018; España-Rodríguez *et al*., 2021).

Among the most used substrates in the production of edible oyster mushrooms, the following stand out: corn stover, wheat straw and sugarcane bagasse, which, according to what was reported by Ruilova-Cueva and Hernández-Monzón (2014), have contents of cellulose between 42%-52%, hemicellulose of 16%-27% and lignin of 7% to 14%. In this context, Gaitán-Hernández and Silva-Huerta (2016) tested oat straw, whose cellulose, hemicellulose and lignin contents are within the mentioned range, which was suitable for the production of *Pleurotus* sp.; with this substrate, the production parameters were 120.3% (±15.4) in biological efficiency (BE), 1.6% (±0.2) production rate (PR) and 27.7% (±3.5) in yield (Y), with diameters of pilei between 5 and 9.9 cm.

Based on the above references and the successful results of the use of glochids within the composition of the substrate for the production of mycelium of *Pleurotus* sp. (De Jesús-Rivera, 2020; De Jesús-Rivera *et al*., 2022), prickly pear glochids meet desirable characteristics for their use as a substrate in oyster mushroom production, consequently, to give added value to this waste of prickly pear production. The prickly pear producers of the locality of San Felipe Teotitlán, municipality of Nopaltepec, show great interest in reducing the environmental pressure generated by the residues of this agricultural activity.

In the search for options that produce added value to the fruit glochids, the present research aimed to evaluate the prickly pear glochids as an improvement component of substrate to produce *Pleurotus* sp., through parameters of productivity and economic feasibility as an alternative for use.

Materials and methods

Characteristics of the experiment and treatments

Prickly pear glochids obtained from the 2018 and 2019 production cycle, from the locality of San Felipe Teotitlán, Municipality of Nopaltepec, State of Mexico, were used. According to Ulloa-Leitón *et al*. (2021), the glochids contain 41% (±0.2) cellulose, 41% (±0.2) hemicellulose and 5.27% (±0.2) lignin, with a density of 0.1574 g ml^{-1}.

The mycelium (F2) used was obtained by direct sowing (mycelium-mycelium) in sorghum grains and mixture of ground and whole glochids from the strain of the collection of the Instituto de Ecología, AC (INECOL) (Jesús-Rivera, 2020; De Jesús-Rivera *et al*., 2022). The treatments consisted of mixing oat straw with proportions of ground (EM) or whole (EE) glochids as indicated in Table 1. The control consisted of using only oat straw, the traditional substrate for these production purposes. In total, seven treatments were used in a completely randomized experimental design with six replications.

Table 1. Proportions in percentage of the materials used in the preparation of the substrate by treatment.

Treatment	Oat straw	Whole glochids	Ground glochids
Control	100	0	0
80RA-20EE	80	20	0
70RA-30EE	70	30	0
60RA-40EE	60	40	0
80RA-20EM	80	0	20
70RA-30EM	70	0	30
60RA-40EM	60	0	40

RA= oat stubble; EE= whole glochids; EM= ground glochids.

Substrate preparation

Prior to the preparation of the treatments, the glochids were cleaned, removing the largest debris. In the oat straw, the stubble that contained soil and all material that was different from the required substrate were discarded, and it was divided into portions of 8 to 10 cm. The mixtures of each experimental unit were placed in cloth (organza) bags with a capacity of 6 kg, properly labeled. The dry weights were recorded and the bags were closed, then pasteurized for 20 min at 85 °C (Figure 1).

Figure 1. Preparation of the substrate: a) straw chopping; b) mixing and closing of sacks; and c) pasteurization.

Once pasteurization was complete, the bag was suspended to remove excess water. The sowing and draining area were disinfected with soap and chlorine solution, the shelves were cleaned with antibacterial gel. The drained mixture was dispersed in a sifter in order to bring it to room temperature, then alkalized by sprinkling $Ca(OH)_2$ (Figure 2).

Figure 2. Preparation of the substrate, a) draining, b) cooling, and c) Aakalization with Ca $(OH)_2$.

The mycelium (Figure 3a and 3b) was placed in a container to homogenize it, then sown by interspersing a layer of approximately 5 cm of substrate and a layer of mycelium, until reaching a weight between 2 and 3 kg, in transparent plastic bags of 50x70 cm. Eight holes of 1 cm in diameter were made in the bags to favor aeration, subsequently, the experimental units were closed, labeled and placed on incubation shelves (Figure 3c and 3d). Ambient temperature and humidity data were recorded (Table 2).

Figure 3. Sowing a) homogenized mycelium; b) sowing; c) labelling; and d) incubation area.

Table 2. Records of temperature and humidity during the production stage.

Week	External temperature (°C)	Internal temperature (°C)	Relative humidity (%)
	Incubation period		
1 (8-14)	32.8	29.4	38.1
2 (15-21)	32.3	29	38.7
3 (22-28)	29.1	26	35
	Appearance of primordia		
4 (29-04)	29.1		34.3

Week	External temperature (°C)	Internal temperature (°C)	Relative humidity (%)
		Harvest	
5 (5-11)	29		62.9
6 (12-18)	24.8		85.3
		Rest without irrigation	
7 (19-25)	30		62
		Harvest	
8 (26-2)	25.9		84.1
9 (3-9)	21.4		87.4
10 (10-16)	21.5		83.1

Twenty-one days after the establishment of the experiment, the appearance of primordia began (Figure 4a) and based on this indicator, the irrigations were applied every 12 h to favor the increase in relative humidity. The collection of carpophores occurred nine days after the appearance of primordia, when their gill had thinned edges (Figure 4b). The collected oyster mushrooms were weighed and placed in 500 g bags for sale (Figure 4c).

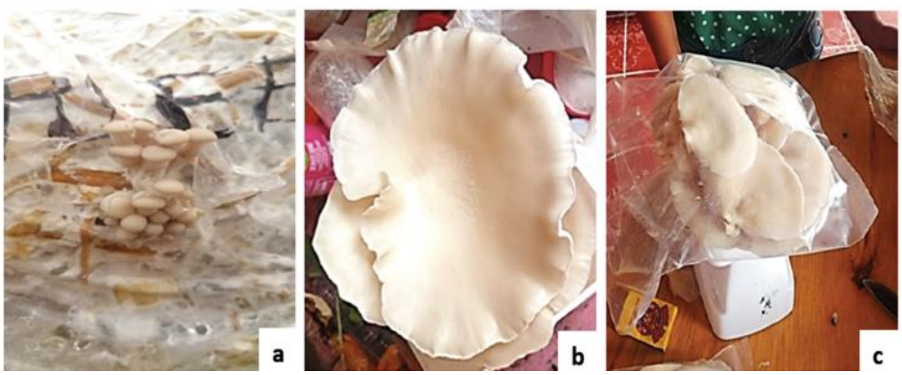

Figure 4. a) appearance of primordia, b) carpophores with thinned edges; and c) carpophores for sale.

Variables evaluated

The production parameters of *Pleurotus* sp. were evaluated based on earliness, biological efficiency, yield and production rate, taking as a reference what was proposed by Gaitán-Hernández *et al*. (2009). Earliness (E): defined as the time that elapses between the day of inoculation and the day on which the first primordia or carpophores appear. It is expressed in number of days.

Biological efficiency (%, BE): it expresses the degree of energy bioconversion from the biodegradation of the substrate, defined by the ratio between the fresh weight of the fruiting bodies and the dry weight of the substrate used for their production for the sum of the harvests (Barba-Chávez and López-Cruz, 2017). BE %= $\frac{\text{Weight of the fresh mushroom (g)}}{\text{Weight of the dry substrate (g)}}$ x 100. Yield (%, Y): it is the ratio in percentage between the fresh weight of the mushroom and the weight of the wet substrate. Y%= $\frac{\text{Weight of the fresh mushroom (g)}}{\text{Weight of the wet substrate (g)}}$ x 100.

Production rate (%, PR): this indicator provides important information on the replacement that exists between each lot that is grown and is related to the effectiveness of the process; through the time of sowing, incubation, fruiting and harvesting. The production rate is the ratio in percentage between biological efficiency and the time required for harvest, that is, it represents daily biological efficiency (Barba-López and López-Cruz, 2017). PR (%)= $\frac{\text{BE}}{\text{Earliness (days)+fruiting period (days)}}$.

Statistical analysis

Because the response variables did not present continuous means, the values of the evaluated parameters were transformed into ranges for the analysis of variance. The means of the treatments and the corresponding standard deviation were estimated, the LSD test was also applied for the corresponding comparison with a confidence level of 95%. Data were analyzed with the statistical package Statistical Analysis Software (SAS) with license number 70074773.

Economic evaluation

The economic evaluation was carried out in order to estimate the profit obtained when alternative materials are used as improvers of the traditional production substrate that is normally purchased. According to the data reported by Gaitán-Hernández (2007) and the experience of the producer, the following parameters were considered: Installed capacity, production per production cycle, net production, costs of inputs for production, cost of substrate per production cycle, current price of the product to the consumer and net income per kilogram of fresh mushroom produced.

Results and discussion

Production parameters

The analysis of the significance of the treatments on the variables evaluated, as well as the test of means LSD, indicated that at least two treatments were significantly different in three of the production parameters (Table 3).

Table 3. Comparison of means and standard deviation of the production parameters evaluated in the production of *Pleurotus* sp.

Treatment	Earliness (days)	Yield (%)	Biological efficiency (%)	Production rate (%)
Testigo RA	30.3(±2.3) a	32.9(±8.1) ab	99.8(±24.5) ab	2.2(±0.5) c
80RA-20EE	25.2(±1.7) c	29.8(±9) ab	101(±30.5) ab	2.5(±0.7) abc
70RA-30EE	27.8(±3) bc	24(±6.9) b	88.6(±25.4) b	2.1(±0.5) c
60RA-40EE	27.5(±2.6) abc	25.4(±3.7) b	98 (±14.4) ab	2.2(±0.4) bc
80RA-20EMx	27.7(±1.4) ab	37.7(±10) a	114.9(±33.7) ab	2.6(±0.8) abc
70RA-30EM	25.7(±3.4) bc	38.2(±9.4) a	124.7(±30.7) a	3(±0.6) a
60RA-40EM	25.8(±3.1) bc	38.3(±10.9) a	132.3(±37.5) a	3(±0.9) ab
Pr> F	0.015	0.019	0.1	0.082

Treatment	Earliness (days)	Yield (%)	Biological efficiency (%)	Production rate (%)
CV (%)	49.45	50.29	53.46	52.96
LSD	12.46	12.67	13.47	13.35

RA= oat stubble; EE= whole glochid; EM= ground glochid; LSD= least significant difference. Different letters in the same column indicate a significant difference with a confidence level of 95%.

In general, treatments with whole or ground glochid showed shorter sprouting time (25.2 to 27.8 days) with respect to the control (30.3 days), with an average of 26.6 days elapsed from sowing to the appearance of primordia, effect that was significant in four of the treatments. For this parameter, there were no differences between mixtures. In oat straw, Gaitán-Hernández y Silva-Huerta (2016) report 23 days of incubation, although in their mixture 80% oat straw-20% corn straw, the earliness was 27 days. The results obtained reveal that the addition of whole or ground glochid in the proportions tested contribute to accelerate the earliness of *Pleurotus* sp.

This production parameter is important because it is an indicator of the functioning of the substrate in terms of accelerating or delaying the production process and according to García-Oduardo *et al*. (2011), this colonization phase is the critical point of oyster mushroom production. Regarding the yield (Y%) parameter, there were no significant differences between treatments; however, the highest percentages were achieved with mixtures with EM, which, on average, reached 38.3% (±10.9) of production with respect to the control with 32.9% (±8.1). Although statistically there were no differences, it is clear that the use of ground glochids reduces the amount of traditional substrate that is frequently purchased and represents savings for the producer.

The results obtained also exceeded those reported by Gaitán-Hernández and Silva-Huerta (2016), who, in their best treatment (mixture 20% corn stover, 80% oat straw), achieved a yield of 31.56%. García-Oduardo *et al*. (2011) consider that substrate formulations in which yields greater than 10% are achieved are viable to be economically exploited. With this criterion, even treatments with whole glochid represent an economically feasible option.

Biological efficiency (BE) was another parameter that showed no significant differences between treatments; however, the highest average BE was obtained with mixtures of ground glochids. These promoted a BE of 124% (±30.7), while that of the control was 99.8% (±24.5). Gaitán-Hernández and Silva-Huerta (2016) obtained BEs similar to those obtained in this experiment when using oat straw substrate, with which they achieved a BE of 120.3% (±15.4) and with their best treatment mixture 20% corn stover-80% oat straw of 139.7% (±3.9).

Michel-Aceves *et al*. (2015) confirm that BEs with values close to or greater than 100% are considered highly profitable and less than 65% unprofitable. In this context, Garzón-Gómez and Cuervo-Andrade (2008) report that the productive quality of a substrate is perceived as acceptable from biological efficiencies of 50%, which coincides with what was confirmed by García-Oduardo *et al*. (2011), concluding that formulations with BE greater than 50% and Y greater than 10% are economically feasible. The BE is an indicator that reflects whether the substrate is suitable for the production of the mushroom and the ability of the mushroom to use nutrients.

Considering these references, it is important to mention that mixtures with whole or ground glochids meet these production parameters so they can be considered viable options for the production of oyster mushrooms. Regarding the indicator of production rate (PR), the treatments with significantly higher PR were achieved with mixtures of EM in the proportion of 30 and 40%, with an average PR of 3%, while the control was 2.2% (±0.5). Gaitán *et al*. (2016) report a PR of 1.6% (±0.2) for oat straw substrate and the best PR in substrate mixture 20% corn stover 80% oat straw with 1.8% daily biological efficiency; for their part, Romero-Arenas *et al*. (2018) achieved a PR of 1.8 in wheat straw substrate. Although in this study the PRs obtained with EM stand out, it is important to mention that the seven treatments have PRs greater than 2, which exceeds the PRs reported by the aforementioned authors.

Economic analysis

Based on the two best treatments that resulted from the experiment, compared to the control, Table 4 shows the impact of the net profit obtained by reducing production costs for substrate. According to the data provided by the producer, they use bags with a capacity of 5 kg of dry substrate (RA) for an installation volume of 30 bags, which demands 450 kg of straw for an annual yield of 180 kg of fresh oyster mushrooms (in three production cycles) at a sale price per kilogram of $70.00. Using the mixture 60RA-40EM results in straw purchase savings of 270 kg with annual profits that increase from $6 137.00 to $9 490.75.

Table 4. Economic comparison of the production costs of *Pleurotus* sp., in common substrate and substrate with 30% and 40% of prickly pear glochids for three production cycles of 42 bags per cycle.

Inputs	100% oat straw		70% straw-30% glochids		60% straw-40% glochids	
	Required quantity	Costs ($)	Required quantity	Costs ($)	Required quantity	Costs ($)
Straw (kg)	126	262.1	88.2	183.5	75.6	157.3
Bag (piece)	126	210	126	210	126	210
Inoculum (200 g bag^{-1})	25.2	1764	25.2	1764	25.2	1764
Lime (kg)	150	180	150	180	150	180
Firewood (roll)	36	252	36	252	36	252
Total cost of inputs ($)		2 668.1		2 589.5		2 563.2
Production cost per kg of fresh oyster mushrooms ($ kg^{-1})		21.2		16.4		14.9
			Revenue ($)			
Oyster mushrooms produced (kg)		125.8		157.9		172.2
Local price per kg of oyster mushrooms ($)		70		70		70
Total revenue ($)		8 805.3		11 054.4		12 054.0

Inputs	100% oat straw		70% straw-30% glochids		60% straw-40% glochids	
	Required quantity	Costs ($)	Required quantity	Costs ($)	Required quantity	Costs ($)
Net profit per kg of fresh oyster mushrooms ($ kg^{-1})		48.8		53.6		55.1
Total annual net profit ($)		6 137.2		8 464.9		9 490.8

It is important to consider that the price of a kilogram of fresh oyster mushrooms varies according to the time of year (Gaitán-Hernández, 2007) and ranges between $30.00 and $45.00; nevertheless, even with this price range, the use of the by-product of the processing of prickly pear as a complement to the traditional substrate would improve the net profit. The potential for edible mushroom production at the rural level is significant because it is a simple process with low implementation costs.

The reality shows that a significant proportion of rural producers have an unstable production due to the lack of economic support and technical advice, added to poor planning and commercialization of the product (Martínez-Carrera *et al*., 2000 and 2007), therefore, the decrease in costs for the purchase of substrate represents an area of opportunity for the producer. On the other hand, the results of this research are conclusive as to that the waste generated by the production of oyster mushrooms can be reincorporated as organic fertilizer (Figure 5) to the prickly pear production system, eliminating the environmental impact caused by its waste of origin.

Figure 5. Substrate remaining from the production of *Pleurotus* sp.

Conclusions

The results of the present research showed strong evidence that the agricultural by-product derived from the processing of the prickly pear, which is currently discarded, can be used as an improvement component of substrate for the production of *Pleurotus* sp. The economic benefits are summarized in savings in production costs and greater net profit with respect to traditional substrates, coupled with the ecological benefits that its use could imply.

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