Investigation note

Generation and basic characterization of bagasse from the mezcal agribusiness in Oaxaca

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Abstract

In Oaxaca, in 2019, 90.1% of the certified mezcal produced domestically was produced, in addition to an unknown amount of non-certified mezcal, which in its production generates waste, bagasse the most important. Although it is currently underutilized in Oaxaca, there are various investigations into its potential, which have been aimed at obtaining various products and metabolites for industrial use. The exact data on the amount generated in the palenques and their characteristics is unknown; however, it is important information since it is the basis for establishing management strategies. In this work, carried out in the Central Valleys region of Oaxaca during 2017, the basic characterization of the solid residues of the mezcal agribusiness by species used is presented, and coefficients that can be applied for general estimation of rapid production are estimated of these residues, and serve as a basis for management strategies. It is concluded that there are differences in the characteristics of the residues and the amount of bagasse generated between the different evaluated species.

Keywords: *Agave angustifolia*, *Agave karwinskii*, *Agave marmorata*, *Agave potatorum*, agro-industrial waste, maguey mezcaleros.

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In Oaxaca, eight of the state's municipalities known as the 'Mezcal Region' are incorporated into the Denomination of Origin 'Mezcal' (DOF, 2018). In the state, 6 437 680 liters of mezcal were produced in 2019, representing 90.1% of the national production of certified mezcal, with a clear trend in the annual increase in production (COMERCAM, 2019) and an unknown quantity of mezcal without certify.

Currently, NOM 070 (DOF, 2017) marks the classification of this drink as ancestral mezcal, artisanal mezcal and mezcal, which vary in their process and equipment for cooking, grinding, fermentation and distillation, the mezcals of the three types of production are predominantly destined for commercialization. In recent years there has been an increase in the production of ancestral and artisanal mezcal, as well as wild species; although the increase is not seen in percentage, due to the amounts of espadin agave mezcal, it does in the amount produced (COMERCAM, 2019), thereby increasing demand and marketing.

In any of the three mezcal manufacturing processes, waste is generated that is currently of little importance in agribusiness, but with a broad environmental impact. The first of these are the leaves, followed by bagasse and stillage. Agave bagasse is the fibrous residue that remains after the 'cone' agave heads are chopped, cooked, rinsed and squeezed to extract the fermentable sugars to obtain the musts that will be used in the production of mezcal (Iñiguez *et al*., 2014).

There are various alternatives for the management of agave bagasse that have been used in the tequila industry and provide it with environmental sustainability, such as those mentioned by Iñiguez *et al*. (2014), who, after separating fiber and marrow, mention that both fractions can be used for potential use, marrow as part of the ruminant diet and fiber for the production of chipboard. The same authors mention the use of bagasse for the treatment of residuals from the tannery industry and from the tequila industry itself, as well as its use for agricultural purposes as a component of growing media in different systems; all of the above with successful results and great potential for escalation.

In Oaxaca, bagasse is still underused, dumped into rivers, streams, or piled up outside palenques and plots (Flores *et al*., 2013), causing a serious problem to the environment due to the large volumes generated and its morphological characteristics, in addition to being a slowly degrading lignocellulosic residue (Alonso and Rigal, 1997). Chávez (2010) affirms that mezcalero agave bagasse has ample potential and advantage, being impregnated with alcohols, when using it as fuel for the generation of renewable energy. Agave bagasses have ample possibilities of being used as an alternative or complementary horticultural substrate to existing ones (Iñiguez *et al*., 2014; Zárate *et al*., 2014; Crespo, 2018).

The producers of mezcal do not record the amount of bagasse generated in the palenques and no research work has been carried out to that end. For tequila agave bagasse, Cedeño (1995) estimated that 40% of the fresh weight of cone becomes bagasse. Some studies evaluating the potential of mezcal bagasse for various uses mention different figures for the generation of waste, without distinction of the species from which it comes and without mentioning the source of obtaining the data (Chávez, 2010; Iñiguez *et al*., 2011; Caballero *et al*., 2013).

Herrera *et al*. (2016) indicate that the evaluation of the generation and characterization of waste represent an important tool to determine the economic, human resource, and infrastructure needs required in management strategies and the design of a treatment system that reduces the impacts negatives of the industry that generates it. The objective of the present work is to generate information on the bagasse production of four species of maguey mezcaleros widely used in Oaxaca and to carry out the basic characterization of their composition and properties.

The work was carried out, during the year 2017, in two palenques of the Santiago Matatlan municipalities (16° 51’ 59.3’’ north latitude 96° 22’ 43.1’’ west longitude), Santa Catarina Minas (16° 46’ 47.4” north latitude 96° 37’ 03.1” west longitude), Santa Cruz Xoxocotlan (17° 02’ 01.3” north latitude 96° 43’ 40.5” west longitude) and San Dionisio Ocotepec (16° 47’ 09” north latitude 96° 18’ 40.6” west longitude), all in the Central Valleys region of the State of Oaxaca. The physicochemical analyzes were carried out in the Soil Laboratory of CIIDIR Oaxaca Unit, in the municipality of Santa Cruz Xoxocotlan.

Four species of mezcalero agave, *Agave angustifolia* Haw., *Agave potatorum* Zucc., *Agave karwinskii* Zucc and *Agave marmorata* Roezl were analyzed. Data were recorded in two production processes of the traditional type of mezcal, for each species of agave. The cones used in the baking phase were weighed, from which a sample was taken to analyze the moisture content (AOAC, 1990). The production process was followed until obtaining the solid residue; the amount of liters of mezcal produced in the first distillation was recorded.

The bagasse obtained was determined field density (DDC) according to the technique described by the Test Methods for Examination of Composting and Compost (TMECC 3.01-C, 2001), the pile was covered to calculate its volume and subsequently estimate the weight produced. Three representative samples were taken from each bagasse pile for analysis. The proportion of fiber and marrow was quantified according to that described by Iñiguez *et al*. (2011), dry matter and humidity were also determined by the gravimetric method (AOAC, 1990), the ash content by calcination in a muffle furnace at 550 °C, the proportion of mass lost in this procedure was considered organic matter (OM) (AOAC, 1990), the total nitrogen (NT) was determined with the microKjeldahl technique (NOM-021-SEMARNAT-2000), the total organic carbon (TOC) was calculated from the OM content, with the Gouleke equation (1977), the carbon/nitrogen ratio (C/N) was calculated based on the TOC and NT contents, the pH and the electrical conductivity (EC) were measured in a bagasse:water suspension with a 1:10 weight/volume ratio, with a HANNA potentiometer (CWMI, 1976).

All measurements were made in triplicate. The data, after checking normality and homogeneity of variances (the data in percentage were transformed with the Arcsen function), were subjected to an analysis of variance and, when it indicated significant differences ($p \leq 0.05$), the Tukey test was used for the separation of the means between agave species. For the comparison of means between the types of grinding and distillation, a Student’s t test was applied. The data was analyzed in the SPSS statistical program version 21.0.

The most used species and of which the majority proportion of mezcal is produced, in the sampled palenques and throughout the state of Oaxaca, is *A. angustifolia* and it is in this that the lowest humidity value is reported at the beginning of the process, being statistically different from *A. potatorum* and *A. marmorata* (Table 1).

Table 1. Characterization of the bagasse of four agave species generated in the production of Mezcal in Oaxaca, Mexico.

Parameter	Species			
	A. angustifolia	*A. karwinskii*	*A. potatorum*	*A. marmorata*
Humidity Ag (%)	64.59 ±3.7 b[††]	68.92 ±4.78 b	77.93 ±9.29 a	79.07 ±1.52 a
Humidity Bag (%)	80.3 ±4.06 a	75.54 ±3.69 a	74.67 ±5.23 a	80.3 ±2.95 a
Fiber (%, bh)	29.97 ±6.54 b	48.27 ±8.39 a	35.82 ±9.16 ab	33.93 ±11.35 b
Marrow (%bh)	70.03 ±6.54 a	51.73 ±8.39 b	64.18 ±9.16 ab	66.07 ±11.35 a
OM (%)	90.21 ±2.65 a	88.4 ±2.88 a	86.57 ±0.97 a	81.84 ±2.58 b
TOC (%)	50.12 ±2.16 a	49.11 ±1.6 a	48.19 ±0.44 a	45.46 ±1.44 b
NT	0.26 ±0.1 a	0.22 ±0.05 a	0.26 ±0.06 a	0.31 ±0.1 a
C/N	196.25 ±4.02 ab	226.03 ±13.13 a	182.33 ±12.27 b	160.47 ±49.42 b
pH	5.42 ±1.48 a	6.01 ±0.56 a	5.43 ±0.96 a	5.19 ±0.2 a
EC (dS m^{-1})	1.32 ±0.09 b	1.5 ±0.29 b	1.33 ±0.12 b	1.92 ±0.35 a
DDC (kg m^{-3} bh)	657.06 ±60.27 a	589.58 ±49.59 a	536.98 ±89.04 b	630.4 ±91.7 ab
DDC (kg m^{-3} bs)	138.35 ±5.63 ab	143.46 ±16.68 a	132.25 ±5.46 ab	122.771 ±16.83 b

Ag= Agave (cone); Bag= bagasse; bh= wet base; OM= organic matter; TOC= total organic carbon; NT= total nitrogen; C/N= carbon/nitrogen ratio; EC= electrical conductivity; DDC= field density; bs= dry base. [††]= different letters in the same row indicate significant statistical difference (Tukey $p \leq 0.05$).

In the variables evaluated in the bagasse, with the exception of the content of NT, humidity and pH, significant differences between species are registered. In the bagasse of the species *A. marmorata* and *A. angustifolia*, a higher CDD and a higher percentage of humidity and marrow are recorded. Iñiguez *et al*. (2011) report that bagasse with the highest marrow content reflects an improvement in physical properties when composted and used as a horticultural substrate, improving the parameters of real density and readily available water.

Bagasse from *A. Karwinskii* has the lowest content of NT and the highest value of the C/N ratio, the latter being statistically different from the value of other bagasse, which would imply a greater contribution of external nitrogen in case of handling by composting, since the recommended value of the C/N ratio to start this process properly is between 25 and 30 (Iñiguez *et al*., 2011), the bagasse of the three remaining species has C/N values close to those reported by Iñiguez *et al*. (2011) of bagasse from two different millings and well above the values reported by Crespo *et al*. (2018) in tequila agave bagasse.

The pH value of bagasse for all species is higher than that reported for *A. tequilana* bagasse by Iñiguez *et al*. (2011) and Crespo *et al*. (2018), but agrees with the value reported by Martínez *et al*. (2013) in bagasse from *A. angustifolia*.

The DDC (bs) value is close to the values reported by Iñiguez *et al*. (2011) in tequila agave bagasse with high marrow content. The concentration of soluble salts, measured as electrical conductivity, is higher and statistically different in *A. marmorata*. Some bagasse composting works report an increase in the value of this parameter in the first 126 to 180 days and a decrease after 180 (Iñiguez *et al*., 2011; Martínez *et al*., 2013). Salinity inhibits the growth of plants and reduces their productivity due to a water deficit, toxicity by the ions that induce it and the nutritional imbalance it causes (Cepeda *et al*., 2014); however, a high value of this parameter in compost intended for use as a substrate can be successfully managed with a controlled leaching program (Barbaro *et al*., 2014). The type of distillation significantly affects ($p\leq 0.05$) the parameters: ash, TOC, NT, C/N and OM (Table 2).

Table 2. Characterization of agave bagasse obtained from two different milling processes and two different distillation processes during the production of mezcal in Oaxaca, Mexico.

Parameter	Distillation		Grinding	
	Mud	Copper	Tahona	Mechanical mill
Fiber (%, bh)	39.78 ±9.24	35.85 ±7.22	35.18 ±7.91	42.39 ±12.27
Marrow (% bh)	60.22 ±9.24	64.15 ±7.22	64.84 ±7.91	57.61 ±12.27
DM (%)	20.94 ±1.85	24.91 ±3.72	22.36 ±3.93	22.58 ±4.75
Ash (%)	11.89 ±1.6	15.18 ±3.75*	14.8 ±2.79*	10.69 ±3.02
TOC (%)	49.21 ±1.47*	47.18 ±2.1	47.38 ±1.56	49.61 ±1.68*
NT	0.23 ±0.01	0.3 ±0.08*	0.27 ±0.06*	0.23 ±0.08
C/N	209.69 ±9.88*	161.41 ±34.28	178.85 ±30.15	218.25 ±17.36*
OM (%)	88.11 ±1.59*	84.42 ±3.75	85.16 ±2.87	89.31 ±3.02*
pH	5.76 ±0.57	5.23 ±0.93	5.02 ±0.6	6.2 ±0.57*
EC (mS m^{-1})	1465.1 ±195.52	1406 ±189.75	1516.54 ±328.84	1473.5 ±238.45
DDC (kg m^{-3} bs)	133.67 ±7.88	133.95 ±12.23	128.9 ±8.79	142.65 ±14.05*

bh= wet base; DM: dry matter; TOC= total organic carbon; NT= total nitrogen; C/N= carbon/nitrogen ratio; OM= organic matter; EC= electrical conductivity; DDC= field density; bs= dry base; *= significant statistical difference (T-student $p\leq 0.05$).

In the distillation, various compounds of interest are recovered, such as ethanol, but also undesirable volatile compounds and high molecular weight compounds that are carried away by steam (Escalante *et al*., 2012), an effect that could occur with nitrogenous compounds, which influences the value of NT.

The distillation process in clay pots with reed pipes leaves the bagasse of the various agave species with lower NT content, compared to the distillation process in copper stills. The bagasse obtained from the distillation in mud also shows a higher value of OM and TOC, consequently, it modifies the value of the C/N ratio, which may explain that the bagasse obtained from the distillation in mud has a lower value of this parameter. The effect on the OM and TOC values could perhaps be due to some process of mass transfer due to the difference in concentrations and the heat interaction of the materials involved (Cengel, 2016). There are no studies that have reported and explained this difference.

By the type of milling, significant differences ($p \leq 0.05$) were registered in the contents of: ash, TOC, C/N, OM, pH and DDC (bs). Iñiguez *et al*. (2011) indicate that the crushing procedure for agave cones influences the amount of fiber and marrow that bagasse contains; the same authors report that the bagasse with the highest percentage of marrow contains a lower TOC than the bagasse with the least marrow, coinciding with the results reported in this work (Table 2).

The NT content is not statistically different for both types of grinding, but the C/N ratio is, due to the variation in TOC. The OM values in bagasse derived from milling in tahona are lower, compared to those derived from milling in a mechanical mill. This could be due to the fact that in the milling by blades the surface increases, but hinders the extraction of honeys, contrary to the pressure exerted in the grinding by friction of stone (tahona), which is not efficient in the generation of surface, but if in the extraction of honeys (Michel, 2004), which makes the fermentation process more effective, since milling is a critical point in the process of making mezcal, due to its influence on the yield of the finished product (Duran and Pulido, 2007) and with it the decrease of the residual organic matter. The effects of milling on the amount and composition of residues in the mezcal agribusiness have not been studied to date.

The most widely used species for the production of mezcal is also one of the largest amounts of bagasse generated in relation to the raw material (bh) (Table 3).

Table 3. Values generated as indicators to quantify solid agave bagasse residues in the mezcal manufacturing process in Oaxaca.

Coefficient	Unit	Species			
		A. angustifolia	*A. karwinskii*	*A. potatorum*	*A. marmorata*
A: ag:bg (bh)	%	75.06 ±23.63	75.89 ±7.69	38.41 ±21.35	61.71 ±3.23
B: ag:bg (bs)	%	44.82 ±13.98	49.03 ±22.74	42.45 ±6.45	42.45 ±22.06
C: mzc:ag (bh)	L kg^{-1}	0.135 ±0.01 a	0.122 ±0.01 a	0.043 ±0 b	0.058 ±.03 b
D: mzc:ag (bs)	L kg^{-1}	2.63 ±0.45	3.5 ±1.46	5.09 ±2.05	3.74 ±1.67
E: ag:mzc (bs)	kg L^{-1}	7.41 ±0.61	8.22 ±0.68	23.39 ±1.4	20.49 ±11.64
F: bg:mzc (bh)	kg L^{-1}	5.63 ±2.21	6.21 ±0.46	8.85 ±4.46	12.83 ±7.84

A and B= ag:bg= percentage of agave that transforms into bagasse; C and D: mzc:ag= liters of mezcal obtained; for 1 kg of agave; E= ag:mzc kg of agave required to produce 1 L of mezcal; F= bg:mzc= kg produced from bagasse per 1 L of mezcal; bh= wet base; bs= dry basis.

If the species are analyzed separately, the percentage of bagasse generated in bh is different from that reported by Cedeño (1995) of approximately 40% of fresh cone, except for *A. potatorum*, which has a close value. For species *A. angustifolia* and *A. karwinskii*, between 7.4 kg and 8.2 kg of agave (bh) are required to produce one liter of mezcal, a value lower than that reported by Chavez (2010) and Caballero *et al*. (2013), of 15 and 12.7 kg, respectively; however, the amount of *A. potatorum A. marmorata* raw material needed to produce one liter of mezcal is significantly greater than that of the first two species.

The support values to estimate how much bagasse (bh) is produced, based on the number of liters of mezcal obtained (value of F) are not significantly different between the species, however, they are lower in the species *A. angustifolia*, *A. karwinskii* and *A. potatorum*, which are more commonly used than the *A. marmorata* species (Table 3).

So far, the total bagasse produced in the mezcal agribusiness in the state of Oaxaca is difficult to estimate, for various reasons: there are many micro production companies that are not registered with the Mezcal Quality Regulatory Council (2019), for which is not known how much raw material they process and also the species of agave they use; these residues are still not valued economically in the production chain, on the contrary, the producers of mezcal have the expense of disposing of them, which is why many choose to leave it piled up outside their palenques or cultivation land (Flores *et al*., 2013), there is a shortage or absence of field work related to this topic.

Conclusions

The values of the variables in the different species of agave evaluated, even though most of them present significant differences between them, are within the values reported by other authors for mezcalero and tequila bagasse.

The process in general influences the characteristics of the products obtained, and mezcal has a wide variety of combinations in its processes without losing the essence, however, if there are differences in the generation of waste according to the species used.

The production of maguey mezcalero bagasse generated during the production of mezcal, as well as its composition and physicochemical characteristics, vary depending on the agave species, the type of grinding and distillation used.

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