J. Adv. Educ. Sci. Humanit. (July - December 2023) 1(2): 7-12
https://doi.org/10.5281/zenodo.14602136

JAESH
JOURNAL OF ADVANCES IN EDUCATION, SCIENCES AND HUMANITIES

ORIGINAL ARTICLE

Development and evaluation of sorghum-based spirits with potential for whisky production

Desarrollo y evaluación de aguardientes a base de sorgo con potencial para la producción de whisky

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Received: 22 March 2023 / Accepted: 19 June 2023 / Published online: 31 July 2023

Abstract A spirit was developed from sorghum to evaluate its potential application in whisky production. An acid hydrolysis process was employed at a pressure of 1.3 atm for four hours at 124 °C to extract nutrients from the grain. The resulting culture medium, maintained at 30 °C, was filtered and neutralized before adding *Saccharomyces cerevisiae* yeast for alcoholic fermentation. The spirit was obtained by distilling the fermented medium. The alcohol content, acidity, and pH of the sorghum spirits and the sorghum and corn mixtures were determined. The results showed that the sorghum flour's particle size significantly influenced alcohol yield, with the lowest yield associated with larger particle sizes (1000-2000 µm). The alcohol yield of the spirits obtained from flour mixtures showed no significant differences. However, the 50% sorghum and corn flour mixture tended to increase this parameter compared to the other spirits. Sensory evaluators rated the spirits made with a 1:1 mixture of sorghum and corn flour as "Acceptable," suggesting its potential as a raw material for whisky production.

Keywords spirits, sorghum, corn, sensory evaluation, whisky.

Resumen Se desarrolló un aguardiente a partir de sorgo con el objetivo de evaluar su posible aplicación en la elaboración de whisky. Para la extracción de nutrientes del grano se empleó un proceso de hidrólisis ácida a presión de1,3 atm durante cuatro horas a 124 °C. El medio de cultivo resultante, mantenido a 30 °C, fue filtrado y neutralizado previo a la adición de la levadura *Saccharomyces cerevisiae* para su fermentación alcohólica. El aguardiente se obtuvo mediante destilación del medio fermentado. Se determinó el grado alcohólico, acidez y pH de los aguardientes de sorgo y de las mezclas de sorgo y maíz. Los resultados mostraron que el tamaño de las partículas de la harina de sorgo tuvo una influencia significativa en el rendimiento de alcohol, siendo el menor rendimiento asociado al tamaño de partículas más grande (1000-2000 µm). El rendimiento alcohólico de los aguardientes obtenidos a partir de mezclas de harinas no presentó diferencias significativas, aunque la mezcla de harina de sorgo y maíz al 50 % mostró una tendencia a incrementar este parámetro en comparación con los demás aguardientes. El aguardiente elaborado con una mezcla 1:1 de harina de sorgo y harina de maíz fue clasificado como "Aceptable" por los evaluadores sensoriales, lo que sugiere su potencial como materia prima en la producción de whisky.

Palabras clave aguardiente, sorgo, maíz, evaluación sensorial, whisky.

How to cite
García-Mirabal, Y., Ros, O., & García, M. A. (2023). Development and evaluation of sorghum-based spirits with potential for whisky production. *Journal of Advances Education, Sciences and Humanities*, *1*(2), 7-12. https://doi.org/10.5281/zenodo.14602136

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PUBLIS EDITORIAL

Introduction

Cereals are staple foods in many people's diets, especially in developing countries. Their price in the global market has increased due to the use of these crops for biofuel production, primarily bioethanol (Prasad & Ingle, 2019). This process uses the starches and sugars present in cereals, which are fermented and distilled to obtain alcohol. This phenomenon has created direct competition between food production and biofuels, negatively affecting food prices (Prasad & Ingle, 2019).

Barley, an essential ingredient in producing whisky, beer, and other malted products, has not been immune to this effect. This cereal is a significant source of sugars, proteins, dextrins, minerals, vitamins, and other compounds that determine its high nutritional value and the quality of the derived products. It is frequently used as an "adjunct" in production processes to reduce costs and increase profitability (Lukinac et al., 2022).

The increase in malt prices directly impacts the cost of products made from this raw material, such as whisky. This distilled spirit, made from cereals such as barley, wheat, rye, and corn, is obtained through fermentation, distillation, and aging in oak barrels. Due to the high cost of barrels and the long time required for traditional aging, accelerated aging techniques have been implemented (Kelly et al., 2023). These techniques aim to optimize the contact between the spirit and the oak and enhance the extraction of compounds from the wood, thus improving the process (Krüger et al., 2022). The alcohol content of whisky varies between 40 and 62% (Ablin, 2012) and is known as the "water of life" (Tapia, 2008).

To reduce production costs, sorghum emerges as a viable alternative significantly cheaper than barley. This cereal, whose main form of carbohydrate storage is starch, has an average content of 73.8%, mainly composed of amylopectin (70-80%) and a smaller proportion of amylose (20-30%). Genetic and environmental factors influence these proportions, giving sorghum different characteristics depending on its variety (Kang et al., 2022). Nutritionally, sorghum protein is deficient in lysine and threonine while containing excessive levels of leucine and low levels of methionine (Paoletti et al., 2022).

Since the malting of sorghum does not efficiently activate its enzymes, alternative methods, such as acid hydrolysis under pressure, must be used to extract its nutrients. This process, which uses high temperatures, pressure, and acid over a controlled time, breaks down the starch and other compounds in the grain, yielding a suitable medium for fermentation (Feyera, 2021). In this context, this study aimed to develop a spirit from sorghum grain, using acid hydrolysis under pressure as a method for nutrient extraction, to apply it in whisky production.

Methodology

The production of the spirit involved the use of sorghum variety ISIAP-DORADO, cultivated on lands of the Niceto Pérez Cooperative (Sancti Spíritus), and the yeast *Saccharomyces cerevisiae*. The sorghum grains were polished to remove impurities using a polisher (PNO 12-013) and a vacuum cleaner (PNO 12-009). They were then ground in a Pulvex 200 mill, obtaining flours classified as acceptable (250-315 μm), medium (250-1000 μm), and coarse (1000-2000 μm).

Culture media were prepared with 266 g/L of sorghum flour for each particle size, weighed on a Sartorius 31005 technical balance (PNO 11.08.065.01.98), and acidified with H_2SO_4 1 mol/L to pH=1. Three media were also formulated by combining sorghum and corn flour in 75%-25%, 50%-50%, and 100% corn proportions. All media were prepared in duplicate and hydrolyzed in a Shenan autoclave at 1.3 atm and 124°C for 4 hours. After hydrolysis, they were neutralized with NaOH 1 mol/L to pH=5.

The activation of *S. cerevisiae* required 2.5 g of yeast hydrated in 100 mL of distilled water with 10% sucrose, resting for 30 minutes. Each fermentation medium received 30 mL of activated yeast solution, incubated at 30 °C for 72 hours, followed by sedimentation at 4 °C for 24 hours.

To distill the spirit, 500 mL of each fermented medium was taken and subjected to distillation at 100 °C. Fractions of 20 mL were collected until 100 mL per sample was completed. The alcohol content was analyzed by pycnometer according to NC 623 (2008), relating relative density at 20 °C to alcohol percentage by volume and weight.

The sensory evaluation used a five-point ordinal scale, according to NC-ISO 4121 (2005), rating sensory attributes with trained panelists. Samples (Old Premiers whisky, spirit, and Chanceler whisky) were randomly assigned codes, and averages and ranges were calculated (rejectable: 1-1.5; excellent: 4.6-5).

Quantitative data were analyzed using Statistica software (version 7, 2004, StatSoft, Inc., Tulsa, USA), calculating means, standard deviations, and analysis of variance (ANOVA). The Duncan multiple range test was applied with significance $p \leq 0.05$ (López-Planes, 1994).

Results and discussion

Table 1 shows the pH and acidity values of sorghum spirit with different particle sizes and varying concentrations of sorghum flour mixed with corn flour.

No significant differences were observed in the pH values among the analyzed spirits, reflecting the homogeneity in the neutralization levels applied to the different fermentation medium formulations. This result is consistent with the typical behavior of hydrolytic fermentation reactions, which generally cause slight decreases in pH compared to initial values. The obtained pH values fall within the characteristic range for freshly distilled spirits. Similarly, the acidity values (% acetic acid) showed no significant variations and aligned with the acidity levels commonly reported in fresh or newly distilled spirits (Barnes et al., 2022).

Table 1. pH and acidity values of the spirits

Spirit	pH	Acidity (% acetic acid)
Treatment I (Fine)	4.36 (0.03)	9.5 (0.5)
Treatment II (Medium)	4.23 (0.09)	8.3 (0.6)
Treatment III (Coarse)	4.1 (0.05)	7.8 (0.3)
Treatment IV (75% Sf-25% Cf)	4.37 (0.03)	10.3 (0.4)
Treatment V (50% Sf-50% Cf)	4.58 (0.02)	11.3 (0.6)
Treatment VI (100% Cf)	4.48 (0.07)	10.5 (0.8)

Fine: 250 – 315 µm; Medium: 250 – 1000 µm; Coarse: 1000 – 2000 µm.
Sf: sorghum flour; Cf: corn flour.
Mean (Standard deviation); n = 2.

Table 2 shows the results for alcohol production when varying the substrate particle sizes while maintaining a constant concentration. The best spirit yields (expressed as mL of ethanol/g of sorghum) were recorded with particle sizes between 250-315 µm (fine), which reached the maximum value and showed significant differences compared to particles of 1000-2000 µm (coarse) but not compared to particles 1000 µm (medium). This behavior was attributed to the fact that smaller particles allow for greater extraction of essential nutrients, such as starch, and improve flour recovery, optimizing the effectiveness of the hydrolytic treatment under acid hydrolysis at pressure.

Table 2. Alcohol content and yields of spirits obtained from sorghum flours with different particle sizes

Particle size (µm)	Fraction (20 mL)	Alcohol content (%)	Yield (mL of ethanol/g of sorghum)
250 - 315 µm (Fine)	1	29 (1) a	0.17 (0.01) a
	2	10.5 (0.7) d	
	3	3.3 (0.8) gh	
	4	2.4 (0.1) hi	
	5	0.65 (0.07) k	
250 - 1000 µm (Medium)	1	26 (0.3) b	0.15 (0.01) ab
	2	7.4 (0.3) e	
	3	4 (1) g	
	4	1.96 (0.22) hj	
	5	0.97 (0.09) jk	
1000 - 2000 µm (Coarse)	1	23.3 (0.3) c	0.135 (0.001) b
	2	5.95 (0.35) f	
	3	4.15 (0.07) g	
	4	1.97 (0.04) jk	
	5	0.9 (0.1) jk	

Mean (Standard deviation); n = 2.
Different letters between means of the same indicator differ significantly at $p \leq 0.05$.

The flours with particle sizes of 250-315 µm (fine) and 250-1000 µm (medium) were mixed in a 1:1 ratio to substitute for corn flour in spirits, as no significant differences in in ethanol production were observed between them.

Table 3 reports the alcohol content values obtained from hydrolyzed preparations of mixtures of sorghum and corn flours at different concentrations.

Since no significant differences were observed in the alcohol yield between the spirits obtained from 100% corn flour and the 75% sorghum flour and 25% corn flour mixture, the feasibility of implementing spirits production for whisky production using mixtures with sorghum flour was considered.

Table 3. Alcohol content and yields of spirits obtained from mixtures of sorghum and corn flour

Substrate	Fraction (20 mL)	Alcohol content (%)	Yield (mL of ethanol/g of sorghum)
Treatment IV (75% Sf-25% Cf)	1	29,5 (0,7) b	0,17 (0,01) a
	2	10,5 (0,8) d	
	3	2,65 (0,07) fg	
	4	2,4 (0,1) g	
	5	0,77 (0,03) h	
Treatment V (50% Sf-50% Cf)	1	31,1 (0,2) a	0,185 (0,003) a
	2	11,5 (0,1) c	
	3	3,4 (0,6) e	
	4	2,48 (0,03) g	
	5	0,9 (0,1) h	
Treatment VI (100% Cf)	1	29,8 (0,3) b	0,178 (0,001) a
	2	10,85 (0,07) cd	
	3	3,55 (0,07) e	
	4	2,25 (0,07) g	
	5	0,95 (0,07) h	

Sf: sorghum flour; Cf: corn flour.
Mean (Standard deviation); n= 2.
Different letters between means of the same indicator indicate significant differences for $p \leq 0.05$.

Although the alcohol yield did not show significant variations, the spirits tended to increase with a 50% sorghum flour and 50% corn flour mixture, possibly due to the nutrient balance achieved in this proportion. Alcohol yield could be influenced by genetic, environmental factors, and cultivation practices; moreover, processing operations, such as polishing, could impact the grain properties and, consequently, this property.

The sensory evaluation of the spirits from Treatment V, a 1:1 mixture of sorghum flour and corn flour, was conducted according to Walsh (2007), who suggested that sensory evaluation is a quantitative science in which numerical data is collected to determine specific relationships between product characteristics and human perception. This spirit was selected due to its tendency for higher alcohol yield. Table 4 presents the scores obtained for each beverage evaluated by the judges.

Table 4. Evaluation of the sensory quality of the beverages evaluated

Sample (Code)	Parameter	Score	Sensory rating
Old Premiers (534)	Mode	4	Very good
Minimum	2	Acceptable	
Maximum	4	Very good	
Average	3.2	Good	
Spirits (124)	Mode	2	Acceptable
Minimum	1	Rejectable	
Maximum	3	Good	
Average	1.9	Acceptable	
Chanceler (234)	Mode	5	Excellent
Minimum	1	Rejectable	
Maximum	5	Excellent	
Average	3.2	Good	

Conclusions

The particle size of the sorghum flour significantly influenced the alcoholic yield of the spirits, with the lowest yield observed in larger particle sizes. Although no significant differences were detected in the alcoholic yields of spirits obtained from flour mixtures, the equal combination of sorghum flour and corn flour showed a trend toward increased yields compared to the other formulations. The spirits produced with this balanced mixture were classified as "Acceptable", highlighting the potential to continue developing this product by optimizing production processes to improve its quality and sensory acceptance. The alcoholic yield and sensory characteristics support the use of sorghum flour as a viable component for diversifying and expanding whisky production.

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Conflicts of interest

The authors declare that they have no conflicts of interest.

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Data availability statement

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Statement on the use of AI

The authors acknowledge the use of generative AI and

AI-assisted technologies to improve the readability and clarity of the article.

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