REVISTA BIO CIENCIAS
http://revistabiociencias.uan.edu.mx
https://doi.org/10.15741/revbio.12.nesp.e1692
ISSN 2007-3380

Artículo original / Original article

Nutritional properties of defatted and hydrothermally pretreated meal of *Jatropha curcas* fermented in solid-state with *Saccharomyces cerevisiae*

Propiedades nutrimentales de harina desgrasada y pretratada hidrotérmicamente de *Jatropha curcas* fermentada en estado sólido con *Saccharomyces cerevisiae*

Medina-Rodelo, D.P.[1], Quintana-Obregón, E.A.[2], Angulo-Escalante, M.A.[1], Heredia, J. B.[1], Puello-Cruz, A.C.[3], Gutiérrez-Dorado, R.[4]*

[1] Centro de Investigación en Alimentación y Desarrollo (CIAD), subsede Culiacán, km 5.5 Carretera a Eldorado-Culiacán, Sinaloa, México, C.P. 80110, Culiacán, Sinaloa, México. [2] CONAHCYT- Centro de Investigación en Alimentación y Desarrollo (CIAD), subsede de Tecnología de Alimentos de Origen Vegetal, Hermosillo, C.P. 83304, Hermosillo, Sonora, México. [3] Centro de Investigación en Alimentación y Desarrollo (CIAD), subsede Mazatlán, Av. Sábalo Cerritos S/N, S/C, Mazatlán C.P. 82112, Mazatlán, Sinaloa, México. [4]Facultad de Ciencias Químico-Biológicas, Universidad Autónoma de Sinaloa, Calle Josefa Ortiz de Domínguez, esq. Blvd. de las Américas, Cd. Universitaria, C.P. 80013, Culiacán Rosales, Sinaloa, México.

Please cite this article as/Como citar este artículo: Medina-Rodelo, D.P., Quintana-Obregón, E.A., Angulo-Escalante, M.A., Heredia, J. B., Puello-Cruz, A.C., Gutiérrez-Dorado, R. (2025). Nutritional properties of defatted and hydrothermally pretreated meal of *Jatropha curcas* fermented in solid-state with *Saccharomyces cerevisiae*. *Revista Bio Ciencias* 12 (nesp): 4to Congreso Internacional Sobre Inocuidad y Calidad Alimentaria (ANICA), e1692. https://doi.org/10.15741/revbio.12.nesp.e1692

Article Info/Información del artículo
Received/Recibido: July 13th 2024.
Accepted/Aceptado: December 30th 2024.
Available on line/Publicado: March 04th 2025.

ABSTRACT

In this research, the effect of solid-state fermentation on the nutritional properties of defatted *Jatropha curcas* meal was evaluated, with and without hydrothermal treatment application, using *Saccharomyces cerevisiae* (6×10^9 CFU/g), and incubating for 24, 72, and 144 h at 36 °C. The antinutrient content was determined by spectrophotometric methods; the phorbol esters content was evaluated by high-resolution thin layer chromatography; and the nutritional composition was evaluated by proximal analysis. A two-factor (type of treatment and fermentation time) design was used. The response variables were the content of phytates, saponins, phorbol esters, and nutritional content. The meal that had the characteristics of our interest was the one fermented for 144 h without hydrothermal treatment because it presented a significant reduction of 74 % of phytates, and 51 % of saponins, in addition to the fact that no phorbol esters were detected. The protein content (44.50 %) did not have significant changes. Additionally, decreases of 8-15 %, 28-44 %, and 1.6-7 % in fat, fiber, and carbohydrate content, respectively, were observed. Therefore, this fermented meal is recommended to be implemented in balanced diets for *Oreochromis niloticus*.

KEY WORDS: *Jatropha*, Fermentation, Hydrothermal, Yeast, Fish food.

***Corresponding Author:**

Gutiérrez-Dorado, R. Facultad de Ciencias Químico - Biológicas. Universidad Autónoma de Sinaloa. Calle Josefa Ortiz de Domínguez, esq. Blvd. de las Américas, Cd. Universitaria, C.P. 80013 Culiacán Rosales, Sinaloa, México. Teléfono: (667) 713 7860.
E-mail: rgutierrez@uas.edu.mx

https://revistabiociencias.uan.edu.mx
Revista Bio Ciencias
ISSN 2007-3380l
Memorias del
4° Congreso Internacional Sobre
Inocuidad y Calidad Alimentaria

RESUMEN

En este estudio se evaluó el efecto de la fermentación en estado sólido sobre las propiedades nutrimentales en harina desgrasada de *Jatropha curcas*, con y sin aplicación de tratamiento hidrotérmico, utilizando *Saccharomyces cerevisiae* (6×10^9 CFU/g) e incubación durante 24, 72 y 144 h a 36 °C. El contenido de antinutrientes se determinó por métodos espectrofotométricos, por cromatografía de capa fina de alta resolución se evaluó el contenido de ésteres de forbol y la composición nutrimental por análisis proximal. Se empleó un diseño bifactorial (tipo de tratamiento y tiempo de fermentación) con variables de respuesta contenido de fitatos, saponinas, ésteres de forbol y contenido nutrimental. La harina que tuvo las características de nuestro interés fue la que solamente se fermentó por 144 h sin tratamiento hidrotérmico debido a que presentó una reducción significativa del 74 % de fitatos, 51 % de saponinas, además de que no se detectaron ésteres de forbol. El contenido de proteínas (44.50 %) no tuvo cambios significativos. Además, se observaron disminuciones entre el 8 – 15 %, 28 – 44 % y 1.6 – 7 % en el contenido de grasa, fibra y carbohidratos, respectivamente. Por lo tanto, se recomienda esta harina fermentada para implementarse en dietas balanceadas para *Oreochromis niloticus*.

PALABRAS CLAVE: *Jatropha*, Fermentación, Hidrotérmico, Levadura, Alimento para peces

Introduction

Plant-based ingredients are suitable for fish feed formulation, with oilseed meals standing out. The use of plant proteins has been investigated for various commercial fish species, as these food sources offer a higher content of proteins, amino acids, and fatty acids than those of animal origin (Mondal & Payra, 2015). However, the use of oilseed meal in aquaculture feed is limited by the low content of essential amino acids and the presence of antinutritional factors (Ghosh & Mandal, 2015). Due to the expansion of aquaculture activity, there is a need to seek alternative plant-based protein sources to replace fishmeal in aquaculture diets (Moss *et al*., 2019). Fishmeal in diets enhances quality and accelerates growth due to its palatability, better absorption, digestion, and nutrient uptake (Hodar *et al*., 2020). Fish consumption has increased from 5.2 kg per capita in 1961 to 19.4 kg in 2017, with an average annual growth rate of 2.4 % (FAO, 2020). Hence, it is important to have an alternative to partially replace fishmeal with plant-based meals, such as *Jatropha curcas*.

https://revistabiociencias.uan.edu.mx
Revista Bio Ciencias
ISSN 2007-3380
Memorias del 4° Congreso Internacional Sobre Inocuidad y Calidad Alimentaria
ISSN 2007-3380

Jatropha curcas is a plant native to Mexico and continental America (Achten *et al*., 2010), found in tropical and subtropical climates, and is resistant to high temperatures (da Schio, 2010; Makkar & Becker, 2009). This plant is considered an oilseed due to its high oil content, with at least 50 % oil, making it highly promising for biodiesel production (Gomes *et al*., 2018). The meal obtained after oil extraction is considered nutrient-rich due to its high protein content. However, toxic and antinutritional compounds in raw *Jatropha* limit its employment in diets for feeding several animal species (Abasubong *et al*., 2023). Therefore, it is necessary to apply a detoxification process, such as solid-state fermentation (SSF). Due to its low production cost and high nutritional value, agro-industrial waste from oilseed crops can be considered suitable substrates for fermentation (Dharmakar *et al*., 2022).

SSF is a microbial process that involves the breakdown and transformation of toxic compounds into products that promote the growth of microorganisms (Krishna 2005; Lizardi-Jiménez & Hernández-Martínez 2017). Additionally, it has been reported that the use of plant protein fermented with *Saccharomyces cerevisiae* does not have negative effects on growth, immunity, and stress resistance in various fish species (Hassaan *et al*., 2015; Plaipetch & Yakupitiyage, 2014; Soltan *et al*., 2015). Moreover, *S. cerevisiae* is a yeast with a mechanism similar to probiotics as it increases the secretion of extracellular enzymes, proteases, and amylases, as well as improving nutrient digestibility, which leads to increased growth and feed efficiency in Nile tilapia (Ahmadifar *et al*., 2020; Van-Doan *et al*., 2020).

This study aims to characterize defatted *J. curcas* meal fermented in solid-state with *S. cerevisiae*, with and without the application of a hydrothermal pretreatment. The results obtained from this work can be used for the implementation of fermented defatted *J. curcas* meal in the production of balanced aquaculture feed, specifically for Nile tilapia.

Materials and Methods

Sample preparation

J. curcas fruits were collected in Ejido de la Campana (24° 53’52.3” N; 107° 27’ 18.3” W and 94 masl) in Culiacán, Sinaloa, Mexico, during September 2021 to January 2022. Fruits were transported to the Bioresources Laboratory at the Research Center for Food and Development (CIAD) in Culiacán subsede, Sinaloa, Mexico. The fruits were then dried at ambient temperature (25 – 33 °C) to facilitate the removal of the shell and testa. A sheller (REINMAC) and a testa remover (REINMAC) were used for this process. The remaining testa was manually separated to obtain the kernel, which was then subjected to a cold press (KOMET DD 85G) for partial oil extraction, resulting in a partially defatted meal with a fat content of 58.96 %. Finally, the meal underwent a maceration process for 13 days with hexane at a 1:3 ratio to remove the remaining oil. The resulting defatted *J. curcas* meal (MJc), with a fat content of 15.84 %, was placed in an oven (TERLAB) for 5 hours at 70 °C to evaporate the remaining solvent and stored at 4 °C until its respective use.

https://revistabiociencias.uan.edu.mx
Revista Bio Ciencias
ISSN 2007-3380l
Memorias del
4° Congreso Internacional Sobre
Inocuidad y Calidad Alimentaria

Solid-state fermentation (SSF)

SSF was carried out following the methodology of Medina-Rodelo *et al*. (2023). Before fermentation, one MJc batch was hydrothermally treated and compared to a non-treated batch. A total of 120 g of MJc was placed in 500 mL Erlenmeyer flasks, inoculated with 19.5 mL of *S. cerevisiae* (6 x 10^9 CFU/g), and 72 mL of distilled water (60 % humidity) was added. The mixture was manually homogenized, and the flask openings were sealed with an airlock. The samples were incubated (Incubator IC603CW, Yamato) at 36 °C for 24, 72, and 144 hours. After the incubation period, the samples were placed in an oven (TERLAB) at 65 °C for 24 hours to stop microbial growth. The experiment was performed in duplicate (**Figure 1**).

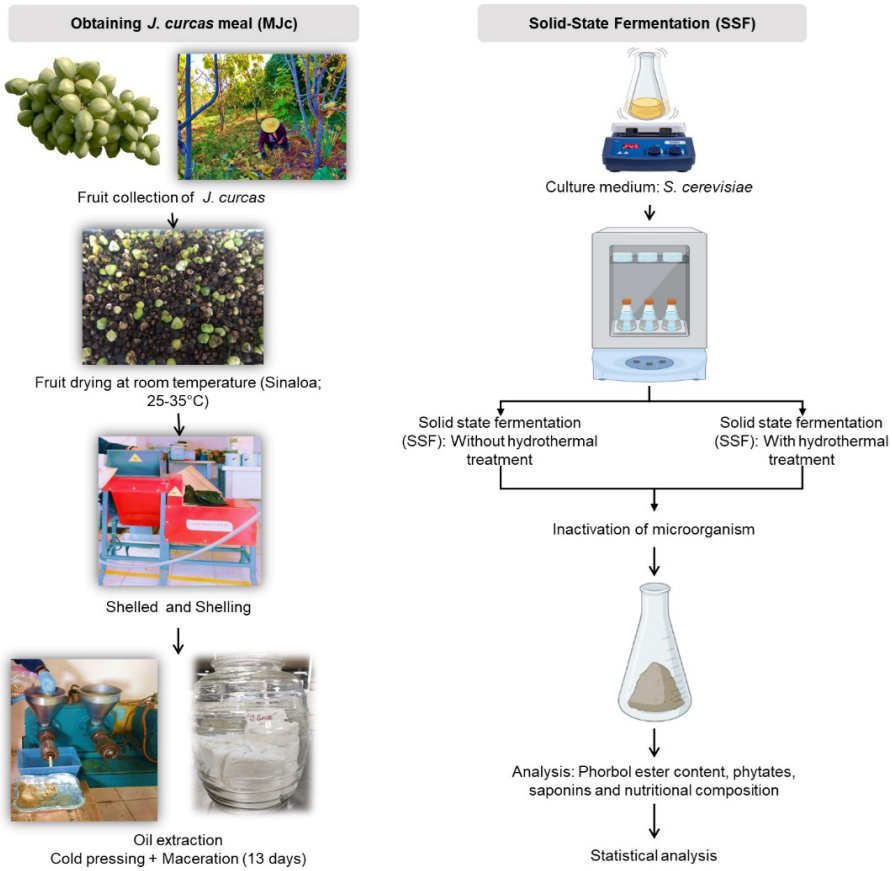

Figure 1. General outline of the research work: obtention of defatted *J. curcas* meal (MJc) and solid-state fermentation process and corresponding analyses.

https://revistabiociencias.uan.edu.mx
Revista Bio Ciencias
ISSN 2007-3380l
Memorias del 4° Congreso Internacional Sobre Inocuidad y Calidad Alimentaria

Quantification of phorbol esters

Pherbol esters quantification was carried out according to the methodology described by Makkar *et al*. (2007) and Devappa *et al*. (2013). One gram of each sample was weighed, and 10 mL of HPLC-grade methanol (SIGMA Aldrich) was added. Then, the mixture was placed in an ultrasonic bath (Model 2800 Branson) at 240 W for 25 minutes at 15 °C. The supernatant was then collected and filtered using filter paper (Whatman No. 40) into a 250 mL round-bottom flask and evaporated to dryness (Mod R-215 Buchi). Afterward, 1 mL of methanol was added, and the sample was sonicated for 2 minutes. Finally, the sample was filtered with a 0.45 µm acrodisc (Millex) and collected in an amber vial. To carry out the High-Performance Thin-Layer Chromatography (HPTLC) analysis, a semi-automatic applicator [Limonat 5, CAMAG (chromatographic chamber)] was used, and 6 µL of the sample was injected into 20 x 10 cm TLC Silica Gel 60 F254 aluminum plates in 85 mm long bands. The plates were placed in a chromatographic chamber (CAMAG), previously saturated for 20 minutes, with a mobile phase of acetone-petroleum ether 4:6 (v/v). The plates were visualized in a UV light chamber (Cabinet 4, CAMAG) at 254 and 366 nm. A densitometric scan was then performed with a TLC scanner (TLC Scanner 4, CAMAG) with an absorbance wavelength of 280 nm using deuterium and tungsten lamps. The concentration of phorbol esters (PE) was calculated using a calibration curve of phorbol-12-myristate-13-acetate (PMA), which is considered a standard (Medina-Rodelo *et al*., 2023). Finally, derivatization was performed using Liebermann's reagent (vanillin-sulfuric acid solution).

Determination of phytates

Following the spectrophotometric method described by Vaintraub & Lapteva (1988), 0.5 g of each sample was weighed, 10 mL of 3.5 % HCl was added, and the mixture was stirred for 1 hour on a stirring plate (DLAB, Model SK-D1807-S). The mixture was centrifuged (Hermle Labortechnik, Thermo Scientific, Germany) at 3400 rpm for 10 minutes and the pellet was discarded. A 200 µL aliquot of the supernatant was mixed with 2.8 mL of distilled water and 1 mL of Wade reagent. The phytate concentration was determined by spectrophotometry at 500 nm, using a calibration curve from a sodium phytate standard solution (SIGMA Aldrich) (160 µg/mL). Results were reported as equivalents of µg of phytic acid per gram of dry sample.

Saponins determination

Saponins were determined following the methodology described by Hiai *et al*. (1976). A 0.5 g sample was mixed with 10 mL of 80 % aqueous methanol (99.8 % purity, SIGMA Aldrich). The mixture was stirred for 12 hours on a stirring plate (DLAB, Model SK-D1807-S), and centrifuged (Hermle Labortechnik, Thermo Scientific, Germany) for 10 minutes at 10,000 rpm. The supernatant was collected, and the precipitate was resuspended in 80 % aqueous methanol. This process was repeated three times, resulting in a total volume of 25 mL. A 200 µL sample reacted with 50 µL of 80 % methanol and 125 µL of 8 % vanillin reagent (SIGMA Aldrich). While on an ice bath, 2.5 mL of 72 % H_2SO_4 (SIGMA Aldrich) was slowly added, and the samples were vortexed (VORTEX-GENIE 2, Scientific Industries) for 3 minutes. Finally, the samples were heated in a water bath at 60 °C for 10 minutes. The saponin concentration was determined by

https://revistabiociencias.uan.edu.mx
Revista Bio Ciencias
ISSN 2007-3380l
Memorias del
4° Congreso Internacional Sobre
Inocuidad y Calidad Alimentaria

spectrophotometry at 544 nm using a diosgenin calibration curve. Results were reported as µg of diosgenin equivalents per gram of dry sample.

Nutritional composition

Following the AOAC (2001) methodology, the sample nutritional content (ash, crude fiber, fat, and crude protein) was determined. The carbohydrate content was estimated by difference (100 – Σ data obtained from proximate analysis).

Statistical analysis

A two-factor design (fermentation time and type of treatment) was used with three levels of fermentation (24, 72, and 144 h) and two levels of treatment type (no treatment and hydrothermal treatment). This resulted in six treatments derived from the combination of the factor levels. The response variables were the content of phytates, saponins, phorbol esters, and nutritional composition. A two-factor ANOVA was performed, followed by a means comparison using Tukey's test with $\alpha = 0.05$ and Dunnett's test with $p \leq 0.05$ to compare with the control sample, which was raw *Jatropha curcas* meal (unprocessed). The experiment was conducted in duplicate, and the statistical analysis was performed using MINITAB 18.0 software.

Results and Discussion

Effect of fermentation on phorbol esters in MJc

Tables 1 and **2** show the effect of solid-state fermentation (SSF) on the phorbol ester (PE) content in treated (hydrothermal treatment) and non-treated fermented MJc. These tables show the sample retention factors (Rf), which ranged from 0.234 to 0.826 and 0.108 to 0.786. Makkar *et al*. (1997) reported that PEs are present in *J. curcas* within an Rf range of 0.42 to 0.55. Additionally, Medina-Rodelo *et al*. (2023) mention that phorbol-12-myristate-13-acetate (PMA) appears with an Rf of 0.54. The sample chromatograms are illustrated in **Figures 2** and **3**, showing the absence of PEs. Therefore, since the Rf values of our samples do not fall within the reported ranges for PEs, we can conclude that no detection of these PEs was found under the chromatographic conditions used.

Table 1. Chromatographic profile of defatted *J. curcas* meal (MJc) samples without hydrothermal treatment.

Figure	Peak	Rf	Area	Substance
Figure 2a)	1	0.549	0.00551	PMA
Figure 2b)	1	0.234	0.00082	ND
	2	0.826	0.00572	ND
Figure 2c)	1	0.210	0.00050	ND
Figure 2d)	1	0.204	0.00122	ND

Rf: Retention factor, PMA: Phorbol-12-Myristate-13-acetate, ND: Not detected

https://revistabiociencias.uan.edu.mx
Revista Bio Ciencias
ISSN 2007-3380l
Memorias del 4° Congreso Internacional Sobre Inocuidad y Calidad Alimentaria

Table 2. Chromatographic profile of defatted *J. curcas* meal (MJc) samples with hydrothermal treatment.

Figure	Peak	Rf	Area	Substance
Figure 3a)	1	0.549	0.00551	PMA
Figure 3b)	1	0.108	0.00551	ND
	2	0.328	0.00232	ND
	3	0.786	0.00136	
Figure 3c)	1	0.116	0.00466	ND
	2	0.269	0.00243	
Figure 3d)	1	0.111	0.00388	ND
	2	0.261	0.00219	

Rf: Retention factor, PMA: Phorbol-12-Myristate-13-acetate, ND: Not detected

Effect of fermentation on phytates in MJc

The phytate content in raw MJc (unprocessed) was 374.96 µg phytic acid per gram of flour. As shown in **Figure 4**, the phytate content decreased between 16 % and 74 % after fermentation. In contrast, the MJc batch subjected to hydrothermal treatment and SSF showed a reduction in phytates between 55 % and 59 %. Therefore, SSF is considered an effective process for the degradation of this compound. Tanasković *et al*. (2021) used SSF on wheat bran meal and found that as fermentation time increased, there was a reduction in phytates, with a final degradation of 34 %. Similarly, Olukomaiya *et al*. (2020) fermented canola meal with *Aspergillus* species, resulting in a significant reduction in phytate content, which is attributed to the increased activity of enzymes such as phytase due to SSF. Terefe *et al*. (2021) used corn meal for SSF with *Lactobacillus plantarum* and *Saccharomyces cerevisiae*. Unlike our study, they performed SSF over shorter periods (12, 24, 36, and 48 hours), resulting in approximately 67 % phytate degradation. In our study, we used a temperature of 37 °C during SSF, which favored the production of phytases, as phytases can be produced naturally (endogenous phytase) or by microorganisms (exogenous phytase) within a temperature range of 35 °C to 45 °C (Sindhu & Khetarpaul, 2001). Therefore, SSF with *S. cerevisiae* can produce phytase enzymes, which participate in the action of repressible acid phosphatases secreted by yeast cells, enabling the hydrolysis of phytates (Haraldsson *et al*., 2005). Furthermore, the presence of phytases increases the bioavailability of minerals (Vásquez-Villalobos *et al*., 2019).

Effect of fermentation on saponins content

The saponin content in raw MJc (unprocessed) was 1594.04 µg diosgenin equivalents per gram of meal. **Figure 5** shows a reduction in saponins in MJc, regardless of the hydrothermal treatment. A 49-51 % decrease was observed in the non-treated fermented MJc, while in the MJc subjected to hydrothermal treatment, the reduction ranged from 82 to 96 %. Sharath *et*

https://revistabiociencias.uan.edu.mx
Revista Bio Ciencias
ISSN 2007-3380l
Memorias del
4° Congreso Internacional Sobre
Inocuidad y Calidad Alimentaria

al. (2014) fermented defatted *J. curcas* meal and observed a degradation of saponins over time, achieving a 96 % reduction after six days of fermentation using *Rhizopus oryzae* and *Cunninghamella echinulata*. Similarly, Adedayo & Sani (2019) conducted SSF on *Adansonia digitata* seed flour, finding a significant reduction in saponin content. It is also important to note that saponins have a bitter taste, which can lead to a lower preference for foods that contain them (Ocampo *et al*., 2015).

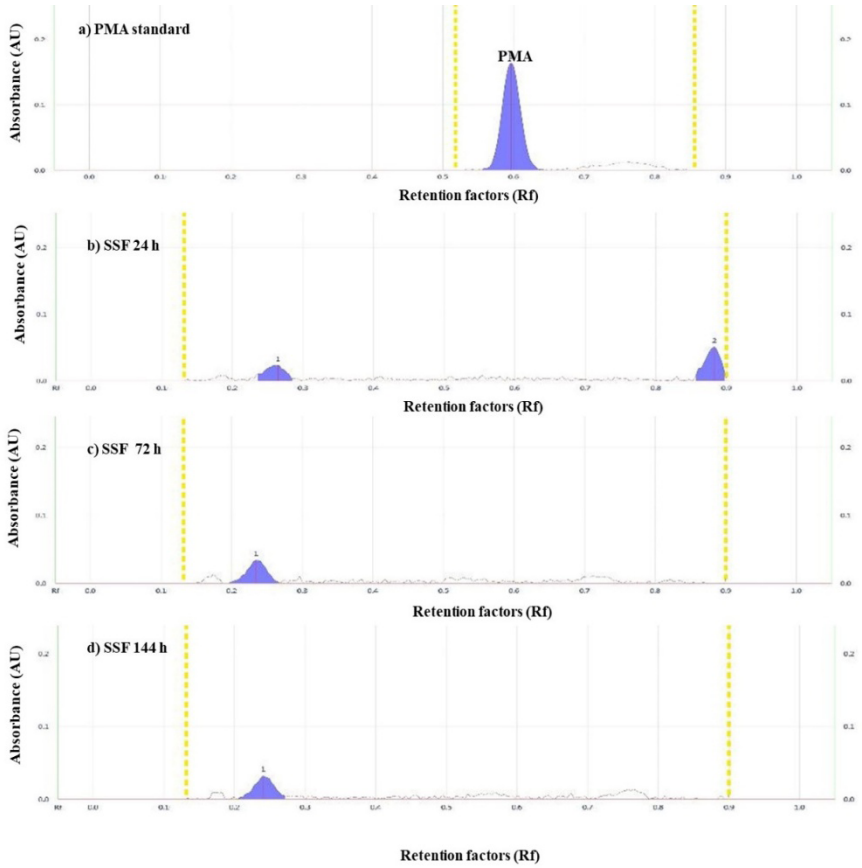

Figure 2. HPTLC chromatograms:

a) Phorbol-12-myristate-13-acetate (PMA); b) defatted *J. curcas* meal (MJc) without hydrothermal treatment fermented for 24 h; c) defatted *J. curcas* meal (MJc) without hydrothermal treatment fermented for 72 h; d) defatted *J. curcas* meal (MJc) without hydrothermal treatment fermented for 144 h.

https://revistabiociencias.uan.edu.mx
Revista Bio Ciencias
ISSN 2007-3380l
Memorias del
4° Congreso Internacional Sobre
Inocuidad y Calidad Alimentaria

Effect of fermentation on the MJc nutritional content

Raw MJc showed a content of protein, fat, ash, crude fiber, and carbohydrates of 40.43 ± 0.22 %, 15.84 ± 0.99 %, 10.07 ± 0.01 %, 9.29 ± 0.21 %, and 24.37 ± 0.86 %, respectively. The protein content was lower than that reported by Martinez-Herrera *et al*. (2006), which ranged from 62 % to 65 %, while the crude fiber and ash content were higher than their reported values (3.9 % to 4.5% and 4.9 % to 8.8 %, respectively).

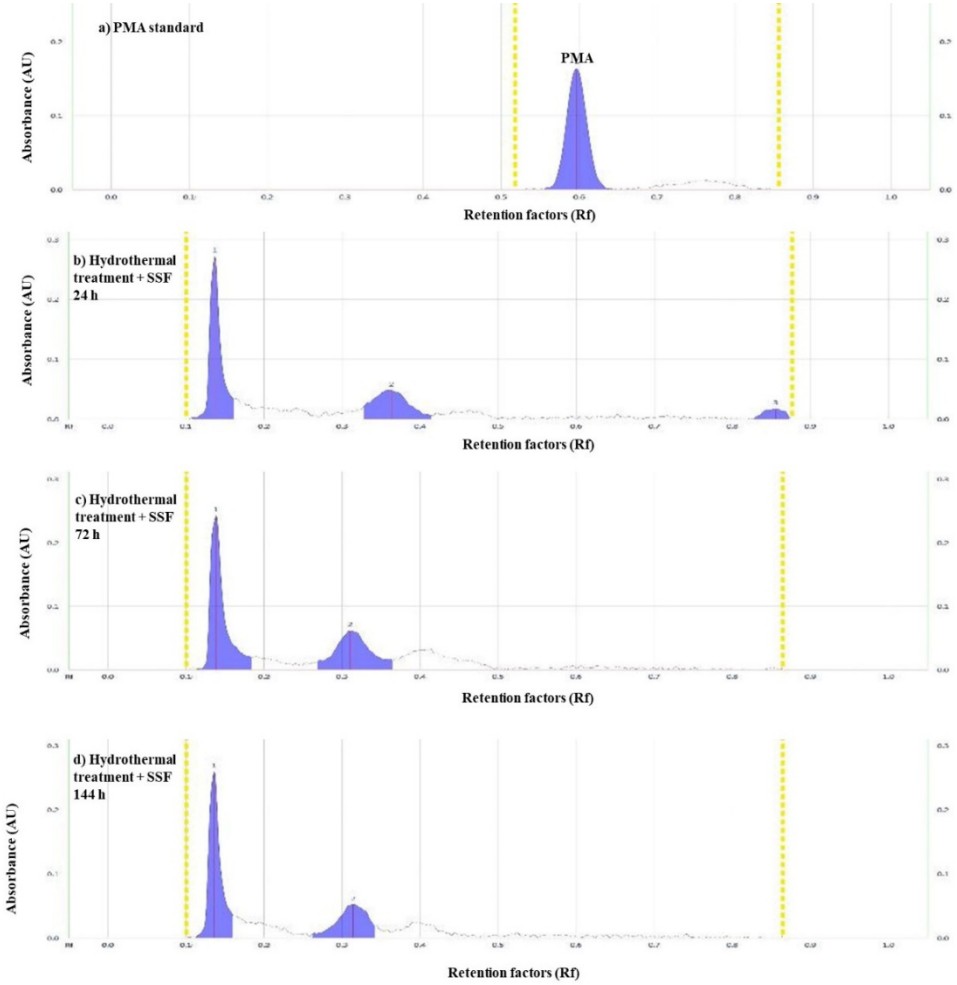

Figure 3. HPTLC chromatograms:

a) Phorbol-12-myristate-13-acetate (PMA); b) defatted *J. curcas* meal (MJc) with hydrothermal treatment fermented for 24 h; c) defatted *J. curcas* meal (MJc) with hydrothermal treatment fermented for 72 h; d) defatted *J. curcas* meal (MJc) with hydrothermal treatment fermented for 144 h.

https://revistabiociencias.uan.edu.mx
Revista Bio Ciencias
ISSN 2007-3380l
Memorias del
4° Congreso Internacional Sobre
Inocuidad y Calidad Alimentaria

The effect of fermentation with and without hydrothermal treatment on the nutritional content of MJc can be observed in **Table 3**. No significant difference in protein content was found in MJc due to SSF, hydrothermal treatment, or the combination of both treatments. This contrasts with the findings of Darwish *et al*. (2012), who applied SSF with *S. cerevisiae* to corn stalks and observed a 7.5 % increase in protein over a 14-day fermentation period. Additionally, the final protein content in our study ranged from 41 to 44 %, which falls within the recommended range (18-50 %) to use in balanced fish feed.

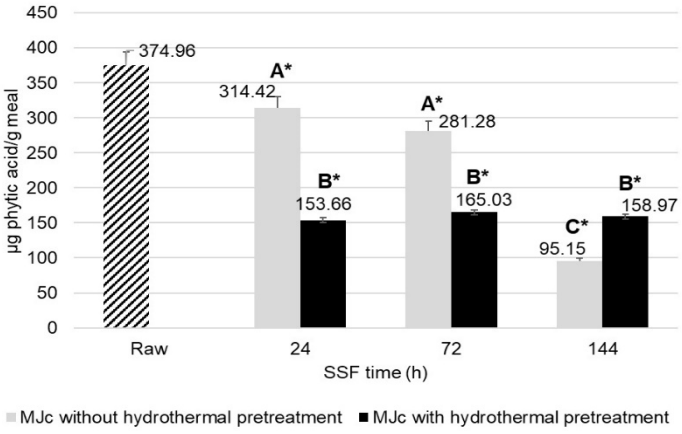

Figure 4. Phytate concentration (µg phytic acid/g meal) in defatted *J. curcas* meal (MJc), with and without hydrothermal treatment, at different fermentation times.

Values are means ± standard deviation (n=2). [A, B, C] Means with different capital superscripts in the corresponding bars are significantly different between samples with and without hydrothermal treatment (Tukey, $p \leq 0.05$). *Means that show significant differences with raw (unprocessed) MJc (Dunnet, $p \leq 0.05$). MJc: defatted *J. curcas* meal.

https://revistabiociencias.uan.edu.mx
Revista Bio Ciencias
ISSN 2007-3380l
Memorias del
4° Congreso Internacional Sobre
Inocuidad y Calidad Alimentaria

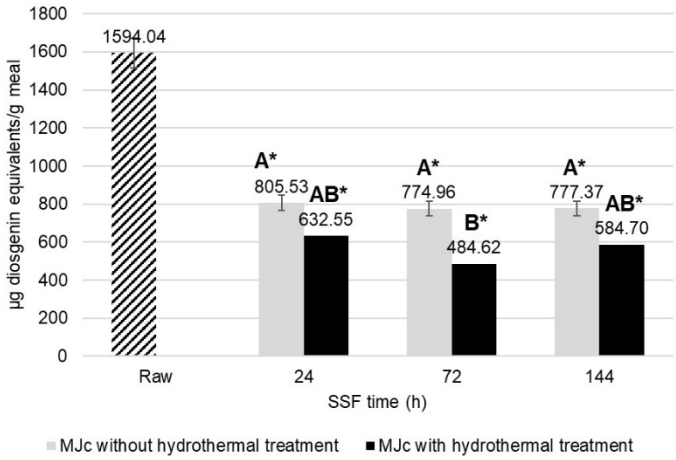

Figure 5. Saponin concentration (µg diosgenin equivalents/g meal) in defatted *J. curcas* meal (MJc), with and without hydrothermal treatment, at different fermentation times.

Values are means ± standard deviation (n=2). [A, B] Means with different capital superscripts on the corresponding bars are significantly different between samples with and without hydrothermal treatment (Tukey, $p \leq 0.05$). *Means that show significant differences with raw (unprocessed) MJc (Dunnet, $p \leq 0.05$). MJc: defatted *J. curcas* meal.

A significant decrease in fat content was observed in non-treated fermented MJc. The fermented MJc showed lower crude fat values (13.45 % to 14.59 %) compared to the raw sample (15.84 %). In contrast, when hydrothermal treatment was applied, there was an increase in fat content (18.19 % to 20.19 % in fermented MJc *vs.* 15.84 % in the raw sample). The fermentation time did not have a significant effect on fat content, regardless of the applied hydrothermal treatment.

In contrast, the crude fiber content showed a significant decrease due to SSF application (approximately 4 %). Hydrothermal treatment did not have a significant effect on this variable. This decrease in crude fiber during SSF can be attributed to the secretion of extracellular enzymes that are capable of degrading fibers, including cellulose and hemicellulose (Darwish *et al*., 2012; Rashad *et al*., 2011). Similar to crude fat content, the fermentation time and hydrothermal treatment had no significant effect on the crude fiber content.

The ash content showed an inverse pattern compared to the crude fat content. A significant increase was observed due to SSF application when the sample was not treated with a hydrothermal treatment. The ash content ranged from 12.33 to 12.66 %, and the raw sample had 10.07 %. However, when the hydrothermal treatment was applied, there was a slight decrease in ash content (9.22 to 9.37 % in fermented MJc) during the fermentation times of 24 and 144 hours. Fermentation time did not have a significant effect on the ash content when the hydrothermal treatment was not applied. However, on heat-treated samples, a reduction in ash content was observed at the previously mentioned fermentation times. The reason for these changes in ash

https://revistabiociencias.uan.edu.mx
Revista Bio Ciencias
ISSN 2007-3380l
Memorias del
4° Congreso Internacional Sobre
Inocuidad y Calidad Alimentaria

content is that hydrothermal treatment allowed the release of minerals through leaching, making them available to microorganisms, which causes a decrease in this nutrient. In contrast, in the non-heated samples, mineral release before SSF did not occur.

Lastly, significant differences were observed in the carbohydrate content across the six treatments without showing any apparent pattern or trend due to SSF, hydrothermal treatment, or a combination of both. This behavior in carbohydrates may be because this nutrient was calculated by subtracting the rest of the nutrients. A decrease of 6 to 8 % in carbohydrate content was observed due to SSF, regardless of the hydrothermal treatment application. This decrease in carbohydrates is attributed to the ability of *Saccharomyces* to utilize hydrocarbon fractions of 12 to 16 carbons as an energy source (Csutak *et al*., 2010).

Table 3. Nutritional content (%, ds) of defatted *J. curcas* meal (MJc), with and without hydrothermal treatment at different fermentation times

Nutritional composition	Without hydrothermal treatment			With hydrothermal treatment		
	SSF time (h)			SSF time (h)		
	24	72	144	24	72	144
Crude protein	41.82 ± 0.19^{a}	43.50 ± 0.12^{a}	44.50 ± 0.21^{a}	41.94 ± 0.20^{a}	41.80 ± 0.31^{a}	41.85 ± 0.20^{a}
Crude fat	14.59 ± 0.04^{ab}	14.45 ± 0.07^{b}	13.45 ± 0.30^{a}	19.79 ± 0.24^{ab}	20.19 ± 0.05^{a}	18.19 ± 0.07^{ab}
Ash	12.33 ± 0.07^{a}	12.66 ± 0.11^{a}	12.52 ± 0.01^{a}	9.22 ± 0.007^{c}	9.95 ± 0.02^{b}	9.37 ± 0.01^{c}
Crude fiber	5.64 ± 0.94^{a}	6.71 ± 1.11^{a}	5.54 ± 0.92^{a}	5.23 ± 0.06^{a}	6.08 ± 0.25^{a}	6.30 ± 0.13^{a}
Carbohydrates	25.62 ± 0.21^{ab}	22.68 ± 0.78^{a}	23.98 ± 0.30^{bc}	23.83 ± 0.28^{c}	21.97 ± 0.35^{c}	24.29 ± 0.24^{abc}

Note: All values are means ± standard deviation (n=2).

$^{a, b, c}$ Means with different superscript lowercase letters on the same line are significantly different (Tukey, $p \leq 0.05$). MJc: defatted *J. curcas* meal.

Conclusions

In this study, the effects of solid-state fermentation (SSF) with *S. cerevisiae* and the application of a hydrothermal treatment before fermentation on defatted *Jatropha curcas* meal (MJc) were observed. After reviewing the response variables, MJc fermented for 144 hours without hydrothermal treatment is of particular interest, as it showed an improvement in nutritional composition, with a reduction in fat, crude fiber, and carbohydrate content. On the other hand, no

significant changes were observed in protein content that could affect the nutritional composition. Additionally, any presence of phorbol esters was detected, and a low concentration of antinutritional compounds (phytates and saponins) was obtained compared to raw (unprocessed) MJc. Therefore, this study broadens the understanding of the benefits of applying biological processes to plant materials, such as MJc, which has significant potential for use in feed production for Nile tilapia.

Author Contributions

"Work conceptualization: Medina-Rodelo, D.P.; Gutiérrez-Dorado, R.; Angulo-Escalante, M.A.; methodology development: Medina-Rodelo, D.P.; Quintana-Obregón, E.A.; Gutiérrez-Dorado, R.; software management: Medina-Rodelo, D.P.; Gutiérrez-Dorado, R.; experimental validation: Medina-Rodelo, D.P.; Gutiérrez-Dorado, R.; results analysis: Medina-Rodelo, D.P.; Gutiérrez-Dorado, R.; data management: Medina-Rodelo, D.P.; Gutiérrez-Dorado, R.; manuscript writing and preparation: Medina-Rodelo, D.P.; writing, review, and editing: Medina-Rodelo, D.P.; Quintana-Obregón, E.A.; Gutiérrez-Dorado, R.; Angulo-Escalante, M.A.; Heredia, J.B.; Puello-Cruz, A.C.; project administration: Medina-Rodelo, D.P.; Quintana-Obregón, E.A.; Gutiérrez-Dorado, R.; Angulo-Escalante, M.A.; Heredia, J.B.; Puello-Cruz, A.C.; funding acquisition: Gutiérrez-Dorado, R.; Angulo-Escalante, M.A.".

"All authors of this manuscript have read and approved the published version".

Funding

This research did not receive external funding.

Ethical declarations

Not applicable.

Informed consent declaration

Not applicable.

Acknowledgments

To CONAHCyT for funding the scholarship awarded to PhD student Dulce Patricia Medina Rodelo. To the Bioresearch and Nutrition research group at the Center for Research in Food and Development (Culiacán subsede).

https://revistabiociencias.uan.edu.mx
Revista Bio Ciencias
ISSN 2007-3380l
Memorias del
4° Congreso Internacional Sobre
Inocuidad y Calidad Alimentaria

Conflict of Interest

The authors declare no conflict of interest.

References

Abasubong, K. P., Gabriel, N. N., Adjoumani, J. J. Y., Okon, A. O., Udo, M. T., Etim, A. A., & Desouky, H. E. (2023). A Dynamic Study of the influence of J*atropha curcas* on Growth and Haematological Indices in Finfish. *In Emerging Sustainable Aquaculture Innovations in Africa, Singapore: Springer Nature Singapore*, 301-323. https://doi.org/10.1007/978-981-19-7451-9_12

Achten, W. M., Nielsen, L. R., Aerts, R., Lengkeek, A. G., Kjær, E. D., Trabucco, A., Hansen, J. K., Maes, W. H., Graudal, L., & Akinnifesi, F. K. (2010). Towards domestication of *Jatropha curcas*. *Biofuels*, *1*(1), 91-107. https://doi.org/10.4155/bfs.09.4

Adedayo, M. R., & Sani, A. (2019). Effect of solid state fungal fermentation on the chemical composition of Adansonia digitata seed. *Covenant Journal of Physical and Life Sciences*, *7*(1), 11-28. (Special Edition). https://journals.covenantuniversity.edu.ng/index.php/cjplsse/article/view/1359

Ahmadifar, E., Sadegh, T. H., Dawood, M. A., Dadar, M., & Sheikhzadeh, N. (2020). The effects of dietary *Pediococcus pentosaceus* on growth performance, hemato-immunological parameters and digestive enzyme activities of common carp (*Cyprinus carpio*). *Aquaculture*, 516, 734656. https://doi.org/10.1016/j.aquaculture.2019.734656

AOAC. (2001). Official Methods of Analysis AOAC International Methods 934.01, 988.05, 920.39 and 942.05. In: AOAC International Arlington, VA, USA.

Csutak, O., Stoica, I., Ghindea, R., Tanase, A.M., & Vassu, T. (2010). Insights on yeast bioremediation processes. *Romanian Biotechnological Letters*, 15 (2), 5066-5071. https://www.researchgate.net/publication/228910865_Insights_on_yeast_bioremediation_processes

Darwish, G. A., Bakr, A., & Abdallah, M. (2012). Nutritional value upgrading of maize stalk by using *Pleurotus ostreatus* and *Saccharomyces cerevisiae* in solid state fermentation. *Annals of Agricultural Sciences*, *57*(1), 47-51. https://doi.org/10.1016/j.aoas.2012.03.005

da Schio, B. (2010). *Jatropha curcas* L., a potential bioenergy crop. On field research in Belize, M.Sc. dissertation. Padua University, Italy and Wageningen University and Research Centre, Plant Research International, the Netherlands. https://docslib.org/doc/8708461/jatropha-curcas-l-a-potential-bioenergy-crop-on-field-research-in-belize

Devappa, R. K., Bingham, J.-P., & Khanal, S. K. (2013). High performance liquid chromatography method for rapid quantification of phorbol esters in *Jatropha curcas* seed. *Industrial Crops and Products*, *49*, 211-219. https://doi.org/10.1016/j.indcrop.2013.04.044

Dharmakar, P., Aanand, S., Kumar, J. S. S., Ande, M. P., Padmavathy, P., & Pereira, J. J. (2022). Solid-state fermentation of sunflower meal using commercial yeast for use as an improved nutrient source in aquafeed. *International Journal of Applied Research*, *8*(3), 375-378. https://doi.org/10.22271/allresearch.2022.v8.i3e.9590

FAO (2020). El estado mundial de la pesca y la acuicultura 2020. La sostenibilidad en acción. Organización de las Naciones Unidas para la Alimentación y la Agricultura, Roma. https://doi.org/10.4060/ca9229es

Ghosh, K., & Mandal, S. (2015). Nutritional evaluation of groundnut oil cake in formulated diets for rohu, *Labeo rohita* (Hamilton) fingerlings after solid state fermentation with a tannase producing yeast, *Pichia kudriavzevii* (GU939629) isolated from fish gut. *Aquaculture Reports*, *2*, 82-90. https://doi.org/10.1016/j.aqrep.2015.08.006

Gomes, T. G., Hadi, S., Costa Alves, G. S., Mendonca, S., De Siqueira, F. G., & Miller, R. N. G. (2018). Current Strategies for the Detoxification of *Jatropha curcas* Seed Cake: A Review. *Journal of Agricultural and Food Chemistry*, *66*(11), 2510-2522. https://doi.org/10.1021/acs.jafc.7b05691

Haraldsson, A. K., Veide, J., Andlid, T., Alminger, M. L., & Sandberg, A.-S. (2005). Degradation of phytate by high-phytase *Saccharomyces cerevisiae* strains during simulated gastrointestinal digestion. *Journal of Agricultural and food Chemistry*, *53* (13), 5438-5444. https://doi.org/10.1021/jf0478399

Hassaan, M. S., Soltan, M. A., & Abdel-Moez, A. M. (2015). Nutritive value of soybean meal after solid state fermentation with *Saccharomyces cerevisiae* for Nile tilapia, *Oreochromis niloticus*. *Animal Feed Science and Technology*, *201*, 89-98. https://doi.org/10.1016/j.anifeedsci.2015.01.007

Hiai, S., Oura, H., & Nakajima, T. (1976). Color reaction of some sapogenins and saponins with vanillin and sulfuric acid. *Planta Medica*, *29*(02), 116-122. https://doi.org/10.1055/s-0028-1097639

Hodar, A.R., Vasava, R.J., Mahavadiya, D.R. y Joshi, N.H. (2020). Fish meal and fish oil replacement for aqua feed formulation by using alternative sources: a review. *Journal of Experimental Zoology India*, *23*(1), 13-21. https://www.researchgate.net/publication/338392541_FISH_MEAL_AND_FISH_OIL_REPLACEMENT_FOR_AQUA_FEED_FORMULATION_BY_USING_ALTERNATIVE_SOURCES_A_REVIEW

Krishna, C. (2005). Solid-state fermentation systems—an overview. *Critical Reviews in Biotechnology*, *25*(1-2), 1-30. https://doi.org/10.1080/07388550590925383

Lizardi-Jiménez, M. A., & Hernández-Martínez, R. (2017). Solid state fermentation (SSF): diversity of applications to valorize waste and biomass. *3 Biotech*, *7*(1), 44. https://doi.org/10.1007/s13205-017-0692-y

Makkar, H., Becker, K., Sporer, F., & Wink, M. (1997). Studies on nutritive potential and toxic constituents of different provenances of *Jatropha curcas*. *Journal of Agricultural Food Chemistry*, *45*(8), 3152-3157. https://doi.org/10.1021/jf970036j

Makkar, H. P., & Becker, K. (2009). *Jatropha curcas*, a promising crop for the generation of biodiesel and value-added coproducts. *European Journal of Lipid Science and Technology*, *111*(8), 773-787. https://doi.org/10.1002/ejlt.200800244

Makkar, H. P., Siddhuraju, P., & Becker, K. (2007). Phorbol esters. In *Plant Secondary Metabolites*, Springer, 101-105. https://doi.org/10.1007/978-1-59745-425-4_1

Martinez-Herrera, J., Siddhuraju, P., Francis, G., Davilaortiz, G., & Becker, K. (2006). Chemical composition, toxic/antimetabolic constituents, and effects of different treatments on their levels, in four provenances of *Jatropha curcas* L. from Mexico. *Food Chemistry*, *96*(1), 80-89. https://doi.org/10.1016/j.foodchem.2005.01.059

Medina-Rodelo, D. P., Quintana-Obregón, E. A., Gutiérrez-Dorado, R., Heredia, J. B., Puello-

https://revistabiociencias.uan.edu.mx
Revista Bio Ciencias
ISSN 2007-3380l
Memorias del 4° Congreso Internacional Sobre Inocuidad y Calidad Alimentaria

Cruz, A. C., & Angulo-Escalante, M. A. (2023). The effects of solid-state fermentation of the defatted *Jatropha platyphylla* meal on antinutritional factors, toxic compounds, and nutritional composition. *Journal of Food Measurement and Characterization*, 1-12. https://doi.org/10.1007/s11694-023-02191-1

Mondal, K., & Payra, P. (2015). A review on use of plant protein sources in diets for fish feed formulation. *Journal of International Academic Research for Multidisciplinary*, *3*(5), 257-264. https://www.jiarm.com/JUNE2015/paper23132.pdf

Moss, A. S., Ishikawa, M., Koshio, S., Yokoyama, S., & Dawood, M. A. (2019). Effects of different levels of marine snail shells in the diets of juvenile kuruma shrimps *Marsupenaeus japonicus* as a source of calcium. *North American Journal of Aquaculture*, *81*(1), 55-66. https://doi.org/10.1002/naaq.10066

Ocampo, R. J., Rosales-Serna, R., González, J. A. R., Alfredo, P., & Martínez, D. (2015). Harina de *Jatropha* para la alimentación animal. Estado del arte en la ciencia y tecnología para la producción y procesamiento de *Jatropha* no tóxica. Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación. Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias. Centro de Investigación Regional Pacífico Sur. Campo Experimental Zacatepec. Publicación Especial No. 60. pp. 74. https://gala.gre.ac.uk/id/eprint/14482/5/14482%20ATKINSON_State_of_Art_on_Science_and_Technology_2015.pdf

Olukomaiya, O. O., Fernando, W. C., Mereddy, R., Li, X., & Sultanbawa, Y. (2020). Solid-state fermentation of canola meal with *Aspergillus sojae*, *Aspergillus ficuum* and their co-cultures: Effects on physicochemical, microbiological and functional properties. *Lwt*, *127*, 109362. https://doi.org/10.1016/j.lwt.2020.109362

Plaipetch, P., & Yakupitiyage, A. (2014). Effect of replacing soybean meal with yeast-fermented canola meal on growth and nutrient retention of Nile tilapia, *Oreochromis niloticus* (Linnaeus 1758). *Aquaculture Research*, *45*(11), 1744-1753. https://doi.org/10.1111/are.12119

Rashad, M. M., Mahmoud, A. E., Abdou, H. M., & Nooman, M. U. (2011). Improvement of nutritional quality and antioxidant activities of yeast fermented soybean curd residue. *African Journal of Biotechnology*, *10*(28), 5504-5513. https://www.ajol.info/index.php/ajb/article/view/94330

Sharath, B. S., Mohankumar, B. V., & Somashekar, D. (2014). Bio-detoxification of phorbol esters and other anti-nutrients of *Jatropha curcas* seed cake by fungal cultures using solid-state fermentation. *Applied Biochemistry and Biotechnology*, *172*(5), 2747-2757. https://doi.org/10.1007/s12010-013-0698-9

Sindhu, S. C., & Khetarpaul, N. (2001). Probiotic fermentation of indigenous food mixture: effect on antinutrients and digestibility of starch and protein. *Journal of Food Composition and Analysis*, *14*(6), 601-609. https://doi.org/10.1006/jfca.2001.1022

Soltan, M. A., Hassaan, M. S., Abdella, M. S., El-Syaad, G. A., & El-Ashry, M. A. (2015). Yeast fermented sunflower meal as a replacer for fish meal in diets of the Nile tilapia, *Oreochromis niloticus*. *Egyptian Journal of Aquatic Biology and Fisheries*, *287*(2394), 1-9. https://doi.org/10.21608/ejabf.2015.2258

Tanasković, S. J., Šekuljica, N., Jovanović, J., Gazikalović, I., Grbavčić, S., Đorđević, N., Sekulić, M. V., Hao, J., Luković, N., & Knežević-Jugović, Z. (2021). Upgrading of valuable food component contents and anti-nutritional factors depletion by solid-state fermentation: A way to valorize wheat bran for nutrition. *Journal of Cereal Science*, *99*, 103159. https://doi.org/10.1016/j.jcs.2020.103159

https://revistabiociencias.uan.edu.mx
Revista Bio Ciencias
ISSN 2007-3380l
Memorias del 4° Congreso Internacional Sobre Inocuidad y Calidad Alimentaria

Terefe, Z. K., Omwamba, M. N., & Nduko, J. M. (2021). Effect of solid state fermentation on proximate composition, antinutritional factors and *in vitro* protein digestibility of maize flour. *Food Science & Nutrition*, *9*(11), 6343-6352. https://doi.org/10.1002/fsn3.2599

Vaintraub, I. A., & Lapteva, N. A. (1988). Colorimetric determination of phytate in unpurified extracts of seeds and the products of their processing. *Analytical Biochemistry*, *175*(1), 227-230. https://doi.org/10.1016/0003-2697(88)90382-X

Van-Doan, H., Hoseinifar, S. H., Ringø, E., Ángeles-Esteban, M., Dadar, M., Dawood, M. A., & Faggio, C. (2020). Host-associated probiotics: a key factor in sustainable aquaculture. *Reviews in Fisheries Science & Aquaculture*, *28*(1), 16-42. https://doi.org/10.1080/23308249.2019.1643288

Vásquez-Villalobos, V. J., Rojas-Padilla, C. R., Luján-Velásquez, M. N., Cholán-Rodríguez, M. A., Mercedes-Chávez, L. A., & Vásquez-Angulo, J. D. (2019). Evaluación de digestibilidad proteica in vivo e in vitro utilizando *Saccharomyces cerevisiae* (*Saccharomycetaceae*) como organismo modelo. *Arnaldoa*, *26*(3), 1125-1142. http://www.scielo.org.pe/pdf/arnal/v26n3/a18v26n3.pdf