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Discarded Sun-dried Potatoes (*Solanum tuberosum* L.) as Untraditional Source of Energy in the Nile Tilapia (*Oreochromis niloticus*) Fingerlings Diets

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ABSTRACT

This study evaluated the effects of incorporating sun-dried discarded potatoes (SDDP) at 0, 15, 30, and 45% inclusion levels into the diets of the Nile tilapia (*Oreochromis niloticus*). A total of 120 fingerlings (174.25 ± 1.71 g) were stocked in 12 aquaria (100 L each) at a density of 10 fish per tank. SDDP contained 8.08% crude protein (CP), 3.06% crude fiber (CF), 0.10% ether extract (EE), 86.66% nitrogen-free extract (NFE), 2.10% ash, and 4,189 kcal/kg dry matter (DM) gross energy. All experimental diets were iso-caloric and iso-nitrogenous. Growth performance parameters—final weight, total gain, average daily gain (ADG), and specific growth rate (SGR)—were significantly ($P< 0.05$) higher in SDDP-fed groups than in the control. Survival rate was 93.33% in the control and 100% in all treated groups. Feed conversion ratio (FCR) and protein efficiency ratio (PER) also improved with SDDP inclusion. Most blood parameters were significantly affected ($P< 0.05$), except for the albumin-to-globulin ratio, creatinine, cholesterol, triglycerides, and bilirubin. Whole-body composition analysis showed significant increases in organic matter (OM), CP, and gross energy, and decreases in moisture, EE, and ash. Energy retention (ER%) increased by 18.79%, 39.99%, and 42.75%, while protein productive value (PPV%) improved by 22.52%, 45.87%, and 53.18% in the D2, D3, and D4 groups, respectively, compared to the control. Feed formulation costs decreased with increasing SDDP levels, accompanied by notable improvements in economic efficiency. These results indicate that replacing yellow corn with SDDP at levels up to 45% enhances growth, nutrient retention, and cost efficiency without adverse effects on fish health or performance.

INTRODUCTION

In Egypt, the aquaculture sector faces increasing challenges due to the scarcity and rising prices of conventional feed ingredients. The high and often unstable cost of soybean meal has further intensified the need for alternative, cost-effective protein and energy sources in fish feed formulations. This has prompted researchers to investigate unconventional, low-cost agro-industrial by-products for aquafeed use.

Previous studies **(Abdel-Hakim *et al.,* 2003, 2010)** have emphasized that feed composition should be tailored to the cultured species, ingredient availability, and economic feasibility. In intensive aquaculture systems, feed accounts for approximately 65–70% of total production costs. Therefore, integrating alternative protein or energy sources from non-traditional ingredients or agro-waste products can reduce production costs and support sustainable fish farming.

Feed cost remains a major constraint to aquaculture growth in many developing regions, particularly where fish feed technology is underdeveloped **(Gabriel *et al.*, 2007; Anene *et al.,* 2021)**. **Faramarzi *et al.* (2012)** stressed the urgency of improving food production systems to address global malnutrition amid rapid population growth. The **World Fish Center (2007)** has highlighted aquaculture development as a promising strategy for bridging the animal protein gap in developing nations. However, the high cost of conventional feeds—especially those containing animal protein—continues to limit accessibility for small-scale farmers **(Jauncey & Ross, 1982; Omoregie & Ogbemudia, 1993)**. As a result, interest has grown in plant-based alternatives such as potato by-products, valued for their nutritional quality and lower cost.

Potatoes (*Solanum tuberosum* L.) are widely cultivated and rank as the fourth most consumed crop worldwide **(Katan & De Roos, 2004; Brar *et al.*, 2017; Khorramifar *et al.*, 2021a, b)**. They are rich in carbohydrates, essential vitamins, and minerals, and can be processed in various forms—fried, mashed, or as chips **(Khorramifar *et al.*, 2022)**. Global potato production exceeds 400 million tons annually **(STAT F, 2017)**, with a large proportion processed into products such as French fries and chips, generating significant waste.

In Egypt, potato production reached nearly 2 million tons in 1999, with about 12.2% discarded as waste **(Ghazalah *et al.*, 2002)**. The metabolizable energy of potato by-product meal (3.2 kcal/g) is comparable to that of yellow corn (3.47 kcal/g) **(NRC, 1993)**. In the United States, potato production contributes $3.7 billion annually, yet less than 50% is consumed fresh **(Schieber & Saldaña, 2009; NASS, 2016)**; the remainder is used for processed products, animal feed, or seed tubers.

Potato nutritional composition varies with cultivar, soil type, and storage conditions but generally contains 70–78% moisture, 16–24% starch, and low fat and protein **(Gamarra *et al.*, 2021)**. Potatoes also supply potassium, calcium, magnesium, fiber, vitamins B6, C, and E, and bioactive compounds such as polyphenols **(Zaheer & Akhtar, 2016)**, which have demonstrated antioxidant, antimicrobial, and anticancer properties **(Brown, 2005; Roleira *et al.*, 2015; Shahidi & Ambigaipalan, 2015)**. Potato peels are particularly rich in phenolic compounds but are typically discarded during processing **(Liu *et al.*, 2015; Akyol *et al.*, 2016)**.

Abd El-Hakim *et al.* (2010) reported that replacing 100% of yellow corn with culled sweet potatoes significantly improved fish growth performance.

Based on this background, the present study was conducted to evaluate the effect of incorporating sun-dried discarded potatoes (SDDP) into the diets of the Nile tilapia (*Oreochromis niloticus*). The experiment assessed growth performance, feed utilization, whole-body composition, hematological parameters, energy retention (ER%), protein productive value (PPV%), and economic efficiency.

MATERIALS AND METHODS

Location

The study was carried out at the Fish Laboratory of the Fish Nutrition and Feed Technology Department, Central Laboratory for Aquaculture Research, Abbassa, Abu-Hammad 44662, Agricultural Research Center, Giza, Egypt, in collaboration with the Animal Production Department, Biological Agriculture Research Institute, National Research Centre.

Experimental design

Four dietary treatments were tested, replacing yellow corn with SDDP at 0% (D1), 15% (D2), 30% (D3), and 45% (D4) inclusion levels. All diets were iso-caloric and iso-nitrogenous, and their effects were evaluated across the measured performance and efficiency parameters.

Experimental design

A total of 120 Nile tilapia fingerlings, with an initial average body weight of 174.25 ± 1.71 g, were acclimated and then randomly assigned to 12 aquaria. Each aquarium had a capacity of 100 liters and contained 10 fish, with three replicates per dietary treatment.

Experimental diets

The design of the different experimental group diets and chemical analysis of the tested diets are presented in Table (1).

Table 1. Composition of the different experimental diets

Ingredient	Experimental diets				
	Zero % SDDP	15% SDDP	30% SDDP	45% SDDP	Price of tone LE
	D_1	D_2	D_3	D_4	
Yellow corn	**45.00**	**30.00**	**15.00**	**00.00**	**12500**
Sun-dried discarded potatoes (SDDP)	**00.00**	**15.00**	**30.00**	**45.00**	**7000**
Wheat bran	**6.00**	**6.00**	**6.00**	**6.00**	**14500**
Protein concentration	**30.00**	**30.00**	**30.00**	**30.00**	**25000**
Soybean meal (SBM)	**18.00**	**18.00**	**18.00**	**18.00**	**33000**
Vegetable oil (sun flower oil)	**0.50**	**0.50**	**0.50**	**0.50**	**50000**
Salt (sodium chloride)	**0.20**	**0.20**	**0.20**	**0.20**	**5000**
Vitamin and Minerals*	**0.30**	**0.30**	**0.30**	**0.30**	**40000**
Price of ton fed (LE)	**20315**	**19490**	**18665**	**17840**	**---**
Price of kg fed (LE)	**20.315**	**19.490**	**18.665**	**17.840**	**---**

** Vit. A (E672) (IU) 876.19, Vit. D3 (IU) 1141.39, Vit. E 114.30, Vit. K3 7.55, Vit. B1 13.71, Vit. B2 11.44, Vit. B6 15.33, Vit. B12 0.03, Niacin 60.96, Calpan 30.48, Folic Acid 3.04, Biotin 0.37, Vit. C 11.44, Selenium 0.27, Manganese 19.04, Iron 9.15, Iodine 0.77, Zinc 76.19, Copper 3.04, Cobalt 0.37, Choline Chloride 457.14, and Antioxidant 95.23 (Vit. vitamin; IU international unit)., Price of tone LE According to 2023.

All tilapia fish were fed the tested diet two times daily (8:00 a.m. and 16:00 p.m) at a level of 3% of live body weight, and the experimental feeding period was continuous for 70 days, extending approximately from the middle of December 2023 till the end of February 2024.

Growth performance and feed utilization parameters

1. Body Weight Gain (BWG):

BWG is calculated by subtracting the initial body weight from the final body weight:

BWG = Final Weight – Initial Weight

2. Survival rate (SR %):

The percentage of fish that survived during the experiment is calculated as:

SR (%) = (Number of fish at the end / Number of fish at the beginning) × 100

3. Specific growth rate (SGR):

SGR represents the growth rate over time and is determined using the natural logarithm of body weights:

SGR (%/day) = [(ln Final Weight – ln Initial Weight) / Number of days] × 100

4. Feed conversion ratio (FCR):

FCR indicates the efficiency of feed usage and is calculated as:

FCR = Total Dry Feed Intake (g) / Total Body Weight Gain (g)

5. Crude protein efficiency ratio (CPER):

This ratio measures how effectively the protein in the feed is converted into body mass:

CPER = Total Body Weight Gain (g) / Total Crude Protein Intake (g)

6. Feed efficiency (FE %):

Feed efficiency shows the percentage of feed converted into body weight:

FE (%) = (Weight Gain / Feed Intake) × 100

7. Mortality rate (%):

The mortality rate is calculated as the percentage of fish that died during the experimental period:

Mortality Rate (%) = (Number of dead fish / Initial number of fish) × 100

8. Protein productive value (PPV %):

PPV evaluates the proportion of dietary protein retained in the fish body:

PPV (%) = [(Final Body Protein – Initial Body Protein) / Total Protein Intake] × 100

Energy retention percentage (ER %)

Energy retention percentage (ER%) was calculated to assess how efficiently the dietary energy was retained in the fish body during the experimental period. The formula used is as follows:

$$ER\ (\%) = [(E - E_0) / EF] \times 100$$

Where:

- **E** = Energy content of the fish carcass (kcal) at the end of the experiment
- **E_0** = Energy content of the fish carcass (kcal) at the beginning of the experiment
- **EF** = Total energy intake from feed (kcal)

This parameter reflects the proportion of dietary energy retained as body energy over the course of the trial.

Blood sampling

Blood samples were collected from the caudal vein of 16 fish using 3mL syringes after anesthesia with clove oil (0.5mL/ L). The samples were placed in clean, dry centrifuge tubes and were kept at room temperature to allow clotting. Subsequently, they were centrifuged at 3000 rpm for 15 minutes. The resulting serum was carefully separated and stored at −20°C until used for biochemical analysis.

Body composition

At the beginning of the experiment, 8 fish were sampled to assess the initial whole-body composition. At the end of the trial, 5 fish from each treatment group were randomly selected for final body composition analysis.

Analytical procedures

The basal diet and fish body composition were analyzed according to **AOAC (2016)**.

Biochemical assays

Serum total protein was determined as described by **Armstrong and Carr (1964)**, **Cannon *et al*. (1974)** and **Witt and Trendelenburg (1982)**. Albumin levels were measured following the methods of **Doumas *et al*. (1971)**, **Tietz (1986)** and **Tietz (1990)**. Globulin concentration was calculated by subtracting albumin from total protein values, and the albumin/globulin (A/G) ratio was obtained by dividing albumin by globulin. Alanine aminotransferase (ALT) and aspartate aminotransferase (AST) were measured according to **Reitman and Frankel (1957)** and **Harold (1975)**. Uric acid and creatinine levels were determined following **Tietz (1990)**. Total cholesterol was analyzed as described by **Allain *et al*. (1974)**, **Ellefson and Caraway (1976)** and **Pisani *et al*. (1995)**. On the other hand, triglycerides were measured according to **Fossati and Prencipe (1982)**. All biochemical parameters were analyzed using commercial diagnostic kits (Spectrum Diagnostics, Egypt) and measured colorimetrically with an Agilent Cary UV-Vis spectrophotometer (100/300 Series), following the manufacturer's instructions.

Calculated data

Gross energy (GE; kcal/kg DM) of the experimental diets and fish body composition was calculated based on the caloric values provided by **Blaxter (1968)** and **MacRae and Lobley (2003)**, using the following energy equivalents: 5.65 kcal/g for crude protein (CP), 9.40 kcal/g for ether extract (EE), and 4.15 kcal/g for crude fiber (CF) and nitrogen-free extract (NFE). Metabolizable energy (ME) was estimated according to **NRC (2011)**, using conversion values of 4.50, 8.15, and 3.49 kcal/g for protein, fat, and carbohydrate, respectively. Additionally, the protein-to-energy ratio (mg CP/kcal ME) was calculated following the guidelines of **NRC (2011)**.

Economical evaluation

Economic assessments of the experimental treatments were conducted to calculate the feed cost required to produce one kilogram of fish weight gain. The cost of the experimental diets was estimated in Egyptian Pounds (L.E.) based on market prices in 2023. The feed cost per kilogram of weight gain was calculated using the following formula:

Cost of 1 kg weight gain (L.E.) = Feed conversion ratio × Cost per kg of feed.

Statistical analysis

The collected data were statistically analyzed using one-way analysis of variance (ANOVA) following the procedures outlined in **SPSS (2020)**. Differences among means were assessed using Duncan’s Multiple Range Test **(Duncan, 1955)** to determine statistical significance.

RESULTS

Chemical analysis of sun-dried discarded potatoes (SDDP) and the other feed ingredients

The results presented in Table (2) show that sun-dried discarded potatoes (SDDP) contained 92.18% dry matter (DM), 8.08% crude protein (CP), 3.06% crude fiber (CF), 0.10% ether extract (EE), 86.66% nitrogen-free extract (NFE), 2.10% ash, 4189 kcal/kg DM gross energy (GE), 339.62 kcal/kg DM metabolizable energy (ME), and a protein energy ratio of 23.79mg CP/kcal ME. These findings indicate that SDDP had higher contents of DM, CF, ash, and NFE compared to yellow corn. However, yellow corn had superior values for organic matter (OM), CP, EE, gross energy, metabolizable energy, and protein energy ratio.

Chemical analysis of different experimental diets

The data presented in Table (3) indicate that all experimental diets were approximately iso-caloric and iso-nitrogenous. Crude protein (CP) content ranged from 29.31 to 29.79% across the four tested diets. Gross energy (GE) values varied between 4576 and 4474 kcal/kg DM, while metabolizable energy (ME) ranged from 367.68 to 357.45 kcal/kg DM. The protein-to-energy ratio ranged from 82.00 to 81.02 mg CP/kcal ME. These values are considered adequate to meet the nutritional requirements of the Nile tilapia.

Table 2. Chemical analysis of sun-dried discarded potatoes (SDDP) and the other feed ingredients used in diets formulations

Item	**Feed ingredients**				
	SDDP	**YC**	**WB**	**SBM**	**PC**
Dry matter (DM)	**92.18**	**90.23**	**90.04**	**90.50**	**96.95**
Chemical analysis on DM basis					
Organic matter (OM)	**97.90**	**98.34**	**94.64**	**93.39**	**93.22**
Crude protein (CP)	**8.08**	**9.15**	**13.66**	**44.00**	**56.43**
Crude fiber (CF)	**3.06**	**2.48**	**8.56**	**3.69**	**2.84**
Ether extract (EE)	**0.10**	**3.75**	**3.81**	**2.83**	**1.55**
Nitrogen free extract (NFE)	**86.66**	**82.96**	**68.61**	**42.87**	**32.50**
Ash	**2.10**	**1.66**	**5.36**	**6.61**	**6.68**

Gross energy kcal/ kg DM	**4189**	**4415**	**4332**	**4684**	**4801**
Gross energy cal/ g DM	**4.189**	**4.415**	**4.332**	**4.684**	**4.801**
Metabolizable energy kcal/ kg DM	**339.62**	**361.27**	**331.97**	**370.68**	**379.99**
Protein energy ratio (mg CP/ Kcal ME)	**23.79**	**25.33**	**41.15**	**118.70**	**148.50**

SDDP: Sun-dried discarded potatoes YC: Yellow corn,SBM: Soy bean meal
WB: Wheat bran, PC: Protein concentration
Gross energy (kcal/ kg DM) was calculated according to **Blaxter (1968)** and **MacRae and Lobley (2003)**. Where, each g CP = 5.65 Kcal, g EE = 9.40 kcal and g CF and NFE = 4.15 Kcal.
Metabolizable energy (ME): Calculated using values of 4.50, 8.15 and 3.49 Kcal for protein, fat and carbohydrate, respectively. Calculated according to **NRC (2011)**.
Protein energy ratio (mg CP/ Kcal ME): Calculated according to **NRC (2011)**.

Table 3. Chemical analysis of different experimental diets

Item	**Experimental diets**			
	Zero% SDDP	**15% SDDP**	**30% SDDP**	**45% SDDP**
	D_1	**D_2**	**D_3**	**D_4**
Dry matter (DM)	**91.35**	**91.65**	**91.93**	**92.23**
Chemical analysis on DM basis				
Organic matter (OM)	**95.19**	**95.12**	**95.06**	**94.99**
Crude protein (CP)	**29.79**	**29.63**	**29.46**	**29.31**
Crude fiber (CF)	**3.00**	**3.22**	**3.31**	**3.40**
Ether extract (EE)	**3.40**	**2.87**	**2.30**	**1.76**
Nitrogen free extract (NFE)	**59.00**	**59.40**	**59.99**	**60.52**
Ash	**4.81**	**4.88**	**4.94**	**5.01**
Gross energy kcal/ kg DM	**4576**	**4543**	**4508**	**4474**
Gross energy cal/ g DM	**4.576**	**4.543**	**4.508**	**4.474**
Metabolizable energy kcal/ kg DM	**367.68**	**364.03**	**360.68**	**357.45**
Protein energy ratio (mg CP/ Kcal ME)	**81.02**	**81.39**	**81.68**	**82.00**

SDDP: Sun-dried discarded potatoes.
Gross energy (kcal/ kg DM) was calculated according to **Blaxter (1968)** and **MacRae and Lobley (2003)**. Where, each g CP = 5.65 Kcal, g EE = 9.40 kcal and g CF and NFE = 4.15 Kcal.
Metabolizable energy (ME): Calculated using values of 4.50, 8.15 and 3.49 Kcal for protein, fat and carbohydrate, respectively. Calculated according to **NRC (2011)**.
Protein energy ratio (mg CP/ Kcal ME): Calculated according to **NRC (2011)**.

The results in Table (4) indicate that final weight (FW), total body weight gain (TBWG), average daily gain (ADG), and specific growth rate (SGR) were significantly ($P < 0.05$) higher in fish fed diets containing 15, 30, and 45% sun-dried discarded potatoes (SDDP) (D2, D3, and D4) compared to the control group (D1). The survival rate (SR) was 93.33% in the control group, with a mortality rate of 6.67%, while groups D2, D3, and D4 showed 100% survival and 0% mortality. Overall, SDDP inclusion had a significant ($P < 0.05$) positive effect on the measured growth performance parameters.

Table 4. Growth performance, specific growth rate and survival ratio of different experimental groups

Item	Experimental diets				SEM	Sign. *P*<0.05
	Zero% SDDP	15% SDDP	30% SDDP	45% SDDP		
	D_1	D_2	D_3	D_4		
Number of fish	**30**	**30**	**30**	**30**	**-**	**-**
Initial weight, g (IW)	**175**	**174**	**173**	**175**	**1.711**	**NS**
Final weight, g (FW)	**302b**	330^{ab}	368^{a}	377^{a}	**12.103**	*****
Total body weight gain, g (TBWG)	127^{b}	156^{ab}	195^{ab}	202^{a}	**12.704**	*****
Duration experimental period	**70 days**					
Average daily gain, g (ADG)	**1.81b**	2.23^{ab}	2.79^{ab}	2.89^{a}	**0.182**	*****
Specific growth rate (SGR)	0.72^{b}	0.89^{ab}	1.12^{ab}	1.16^{a}	**0.074**	*****
Number of fish at the starter	**30**	**30**	**30**	**30**	**-**	**-**
Number of fish at the end	**28**	**30**	**30**	**30**	**-**	**-**
Survival ratio (SR)	**93.33**	**100**	**100**	**100**	**-**	**-**
Number of dead fish	**2**	**Zero**	**Zero**	**Zero**	**-**	**-**
Mortality rate percentages	**6.67**	**Zero**	**Zero**	**Zero**	**-**	**-**

SDDP: Sun-dried discarded potatoes.
a and b: All means in the same row having different superscripts differ significantly ($P<0.05$).
SEM: Standard error of mean, NS: Not significant, *: Significant at $P<0.05$.

Feed utilization of the different experimental groups

Data presented in Table (5) establish that both values of feed intake (FI) and crude protein intake (CPI) significantly ($P< 0.05$) increased with increasing levels of SDDP inclusion in the fish diets. Meanwhile, both values of feed conversion ratio (FCR) and protein efficiency ratio (PER) insignificantly ($P> 0.05$) improved.

Table 5. Feed utilization of the different experimental groups

Item	Experimental diets				SEM	Sign. P<0.05
	Zero% SDDP	15% SDDP	30% SDDP	45% SDDP		
	D_1	D_2	D_3	D_4		
Total body weight gain, g (TBWG)	127^{b}	156^{ab}	195^{ab}	202^{a}	**12.704**	*****
Feed intake (FI), g	501^{b}	529^{ab}	568^{a}	580^{a}	12.32^{4}	*****
Feed conversion ratio (FCR)	**3.94**	**3.39**	**2.91**	**2.87**	**0.220**	**NS**
Feed crude protein %	**29.79**	**29.63**	**29.46**	**29.31**	**-**	**-**
Crude protein intake (CPI), g	149.25^{b}	156.74^{ab}	167.33^{ab}	170.00^{a}	**3.427**	*****
Protein efficiency ratio (PER)	**0.851**	**0.995**	**1.165**	**1.188**	**0.059**	**NS**

SDDP: Sun-dried discarded potatoes.
a and b: Means in the same row having different superscripts differ significantly ($P<0.05$).
SEM: Standard error of mean, NS: Not significant, *: Significant at $P<0.05$.
Significant ($P<0.05$) positive effect on the measured growth performance parameters.

Blood parameters of the different experimental groups

The data presented in Table (6) demonstrate that incorporating sun-dried discarded potatoes (SDDP) into fish diets had a significant effect ($P< 0.05$) on most blood parameters, except for the albumin: globulin ratio, creatinine, cholesterol, triglycerides, and bilirubin, which were not significantly affected ($P> 0.05$). Fish fed the diet containing 45% SDDP (D4) exhibited the highest values of total protein, albumin, globulin, glucose, AST, ALT, uric acid, amylase, and trypsin compared to the control group (D1). The group fed 30% SDDP (D3) recorded the highest albumin: globulin ratio and bilirubin levels but the lowest values of globulin, triglycerides, amylase, and trypsin. In contrast, fish fed 15% SDDP (D2) showed the highest cholesterol and triglyceride levels among all groups.

Table 6. Blood parameters of the different experimental groups

Item	Experimental diets				SEM	Sign. P<0.05
	Zero% SDDP	15% SDDP	30% SDDP	45% SDDP		
	D_1	D_2	D_3	D_4		
Total protein (g/dl)	**2.19^{bc}**	**2.55^{ab}**	**2.02^{c}**	**2.86^{a}**	**0.116**	*
Albumin (g/dl)	**1.38^{b}**	**1.70^{ab}**	**1.42^{b}**	**1.94^{a}**	**0.080**	*
Globulin (g/dl)	**0.81^{ab}**	**0.85^{ab}**	**0.60^{b}**	**0.89^{a}**	**0.047**	*
Albumin: globulin ratio	**1.70**	**2.00**	**2.37**	**2.18**	**0.115**	**NS**
Liver function						
AST (U/L)	**58^{b}**	**134^{a}**	**165^{a}**	**170^{a}**	**16.469**	*
ALT (U/L)	**17.00^{c}**	**29.60^{ab}**	**26.85^{b}**	**31.75^{a}**	**1.780**	*
Kidneys function						
Uric acid (mg/dl)	**0.27^{d}**	**0.66^{c}**	**1.03^{b}**	**1.26^{a}**	**0.114**	*
Creatinine (mg/dl)	**0.21**	**0.25**	**0.25**	**0.21**	**0.011**	**NS**
Other parameters						
Cholesterol (mg/dl)	**95.05**	**102.50**	**83.70**	**88.60**	**4.991**	**NS**
Triglycerides (mg/dl)	**73.55**	**77.20**	**45.30**	**52.50**	**7.960**	**NS**
Amylase (U/L)	**67.25^{ab}**	**72.50^{ab}**	**54.20^{b}**	**77.55^{a}**	**3.566**	*
Trypsin (ng /ml)	**0.90^{ab}**	**1.07^{a}**	**0.78^{b}**	**1.17^{a}**	**0.057**	*
Bilirubin (mg/dl)	**0.31**	**0.32**	**0.35**	**0.31**	**0.009**	**NS**

SDDP: Sun-dried discarded potatoes.
a, b, c and d: Means in the same row having different superscripts differ significantly ($P<0.05$).
SEM: Standard error of mean NS: Not significant *: Significant at $P<0.05$.
AST: Aspartate aminotransferase. ALT: Alanine aminotransferase.

Fish body composition of different experimental groups

The data presented in Table (7) reveal that the Nile tilapia fed diets containing sun-dried discarded potatoes (SDDP) showed a significant increase ($P<0.05$) in body composition parameters, including organic matter (OM), crude protein (CP), and gross energy content. Conversely, moisture, ether extract (EE), and ash content were significantly reduced ($P< 0.05$) compared to the control group.

Table 7. Fish body composition of initial and different experimental groups

Item	Body composition of initial fish	Experimental diets				SEM	Sign. P<0.05
		Zero% SDDP	15% SDDP	30% SDDP	45% SDDP		
		D_1	D_2	D_3	D_4		
Moisture	**73.28**	**72.91^{a}**	**72.65^{b}**	**72.34^{c}**	**72.08^{d}**	**0.098**	*****
Dry matter (DM)	**26.72**	**27.09**	**27.35**	**27.66**	**27.92**	**0.148**	**NS**
Chemical analysis on DM basis		***Chemical analysis on DM basis***					
Organic matter (OM)	**83.82**	**83.98^{d}**	**84.86^{c}**	**85.37^{b}**	**85.70^{a}**	**0.197**	*****
Crude protein (CP)	**57.83**	**59.12^{d}**	**60.47^{c}**	**61.36^{b}**	**62.43^{a}**	**0.366**	*****
Ether extract (EE)	**25.99**	**24.86^{a}**	**24.39^{b}**	**24.01^{c}**	**23.27^{d}**	**0.179**	*****
Ash	**16.18**	**16.02^{a}**	**15.14^{b}**	**14.63^{c}**	**14.30^{d}**	**0.196**	*****
Gross energy kcal/ 100g	**571.05**	**564.71^{b}**	**570.92^{a}**	**572.38^{a}**	**571.47^{a}**	**0.580**	*****
Gross energy cal/ g DM	**5.7105**	**5.6471^{b}**	**5.7092^{a}**	**5.7238^{a}**	**5.7147^{a}**	**0.058**	*****

SDDP: Sun-dried discarded potatoes.

a, b, c and d: Means in the same row having different superscripts differ significantly (*P*<0.05).

SEM: Standard error of mean NS: Not significant *: Significant at *P*<0.05.

Energy retention (ER)% and protein productive value (PPV)%

The results presented in Table (8) indicated that incorporating sun-dried discarded potatoes (SDDP) at different levels into the Nile tilapia diets led to an increase in both energy retention (ER%) and protein productive value (PPV%) compared to the control (D1). Although the increase in ER% was not statistically significant (*P*> 0.05), the improvement percentages were 18.79, 39.99, and 42.75% for D2, D3, and D4, respectively. In contrast, PPV% values significantly increased (*P*< 0.05) by 22.52, 45.87, and 53.18% for D2, D3, and D4, respectively, compared to the control.

Table 8. Energy retention (ER) and protein productive value (PPV) % of different experimental groups

Item	Experimental diets				SEM	Sign. P<0.05
	Zero% SDDP	15% SDDP	30% SDDP	45% SDDP		
	D_1	D_2	D_3	D_4		
Initial weight (IW), g	**175**	**174**	**173**	**175**	**1.711**	**NS**
Final weight (FW), g	**302b**	**330^{ab}**	**368^{a}**	**377^{a}**	**12.103**	*****
Calculation theenergy retention						
Energy content in final body fish (cal / g)	**5.6771^{b}**	**5.7092^{a}**	**5.7238^{a}**	**5.7147^{a}**	**0.006**	*****
Total energy at the end in body fish (E)	**1714**	**1884**	**2106**	**2154**	**86.503**	**NS**
Energy content in initial body fish (cal / g)	**5.7105**					
Total energy at the start in body fish (E_0)	**999**	**994**	**988**	**999**	**9.872**	**NS**
Energy retained in body fish ($E-E_0$)	**715**	**890**	**1118**	**1155**	**90.923**	**NS**
Energy of the feed intake (Cal / g feed)	**4.576**	**4.543**	**4.508**	**4.474**	**-**	**-**

Quantity of feed intake	**501[b]**	**529[ab]**	**568[a]**	**580[a]**	**12.324**	*****
Total energy of feed intake (EF)	**2293[b]**	**2403[ab]**	**2561[ab]**	**2595[a]**	**51.276**	*****
Energy retention (ER) %	**31.18**	**37.04**	**43.65**	**44.51**	**3.539**	**NS**
Calculation the protein productive value (PPV) %						
Crude protein % in final body fish	**59.12[d]**	**60.47[c]**	**61.36[b]**	**62.43[a]**	**0.366**	*****
Total protein at the end in body fish (PR_1)	**178.54**	**199.55**	**225.80**	**235.36**	**9.940**	**NS**
Crude protein % in initial body fish	**57.83**					
Total protein at the start in body fish (PR_2)	**101.20**	**100.62**	**100.05**	**101.20**	**0.989**	**NS**
Protein Energy retained in body fish (PR_3) = ($PR_1 – PR_2$)	**77.34**	**98.93**	**125.75**	**134.16**	**10.359**	**NS**
Crude protein in feed intake (CP %)	**29.79**	**29.63**	**29.46**	**29.31**	**-**	**-**
Total Protein intake (PI), g	**149.25[b]**	**156.74[ab]**	**167.33[ab]**	**170.00[a]**	**3.427**	*****
Protein productive value (PPV) %	**51.82**	**63.12**	**75.15**	**78.92**	**6.070**	**NS**

SDDP: Sun-dried discarded potatoes.
a, b, c and d: Means in the same row having different superscripts differ significantly (P<0.05).
SEM: Standard error of mean NS: Not significant *: Significant at P<0.05.

Economical evaluation of different experimental groups

The data from Table (9) demonstrate that incorporating sun-dried discarded potatoes (SDDP) into fish diet formulations effectively reduced feed costs. The cost per kilogram of feed decreased from 20.315 LE in the control diet (D1) to 19.490, 18.665, and 17.840 LE for diets D2, D3, and D4, respectively. Additionally, net improvement in economic efficiency was recorded at 13.39, 24.01, and 23.85% for D2, D3, and D4, respectively, compared to the control group fed the diet without SDDP.

Table 9. Economical evaluation of different experimental groups

Item	**Experimental diets**			
	Zero% SDDP	**15% SDDP**	**30% SDDP**	**45% SDDP**
	D_1	**D_2**	**D_3**	**D_4**
Costing of kg feed (LE)	**20.315**	**19.490**	**18.665**	**17.840**
Relative to control (%)	**100**	**95.94**	**91.88**	**87.82**
Feed conversion ratio (FCR)	**3.94**	**3.39**	**2.91**	**2.87**
Feeding cost (LE) per (Kg weight gain)	**80.04**	**66.07**	**54.32**	**51.20**
Relative to control (%)	**100**	**82.55**	**67.87**	**63.97**
Net improving in feeding cost (%)	**Zero**	**13.39**	**24.01**	**23.85**

SDDP: Sun-dried discarded potatoes. LE: Egyptian pound
Diet formulation calculated according to the local prices at year 2023, as presented in Table (1).
Feed cost (L.E) FCR×FI. Cost per Kg diet.

DISCUSSION

Sun-dried discarded potatoes (SDDP) were found to contain 92.18% dry matter (DM), 8.08% crude protein (CP), 3.06% crude fiber (CF), 0.10% ether extract (EE), 86.66% nitrogen-free extract (NFE), and 2.10% ash. Their gross energy (GE) was 4189 kcal/kg DM, with a metabolizable energy (ME) value of 339.62 kcal/kg DM and a protein-to-energy ratio of 23.79mg CP/kcal ME. Compared to yellow corn, SDDP had higher levels of DM, CF, ash, and NFE, while yellow corn was superior in organic matter (OM), CP, EE, GE, ME, and protein-to-energy ratio. These findings align with Abd El-**Hakim *et al.* (2010)**, who reported that culled sweet potatoes contained 92.5% DM, 6.1% CP, 1.0% fat, 4.6% ash, 3.87% CF, 76.93% NFE, and 3671 kcal/kg of gross energy.

All experimental diets appeared to be isocaloric and isonitrogenous. The crude protein (CP) content ranged from 29.31 to 29.79% across the four diets. Gross energy (GE) values ranged between 4576 and 4474 kcal/kg DM, while metabolizable energy (ME) values ranged from 367.68 to 357.45 kcal/kg DM. Additionally, the protein-to-energy ratio varied from 82.00 to 81.02mg CP/kcal ME. These values are considered adequate to meet the nutritional requirements of the Nile tilapia, as outlined by the **NRC (1993)**.

Values of final weight (FW), total body weight gain (TBWG), average daily gain (ADG), and specific growth rate (SGR) were significantly (P<0.05) increased in fish fed diets containing 15, 30, and 45% sun-dried discarded potatoes (SDDP) for D2, D3, and D4, respectively, compared to the control group (D1). Furthermore, the survival rate (SR) was 93.33% and mortality rate 6.67% in the control group (D1), while the SR reached 100% and mortality dropped to 0% in all groups that received SDDP (D2, D3, and D4). Generally, the level of SDDP inclusion had a significant (P< 0.05) positive effect on the mentioned performance parameters.

These findings are in line with those reported by **Abd El-Hakim *et al*. (2010)**, who fed the mono-sex Nile tilapia diets containing culled inedible sweet potato root (CSP) as a non-traditional energy source to replace yellow corn energy at 0, 25, 50, and 100% (CSP0, CSP25, CSP50, and CSP100). They observed that replacing 100% of yellow corn energy with CSP significantly improved final weight and weight gain compared to the control and 25% replacement levels, without significant effects on condition factor and survival rate.

Similarly, **Olukunle (2006)** evaluated sweet potato peel meal as a cheaper maize replacement in the diet of African catfish (*Clarias gariepinus*) at inclusion levels of 0, 25, 50, and 75%. He reported better performance in all sweet potato-based diets compared to the control. However, growth performance declined at higher inclusion levels, suggesting that low levels of sweet potato peel were well tolerated by *C. gariepinus*.

Omoregie *et al.* (2009) also incorporated sweet potato peels up to 25% in the diet of the Nile tilapia and found no significant adverse effects on growth or health. Their results confirmed that inclusion levels up to 15% were well tolerated by *O. niloticus*.

On the other hand, **Soltan *et al.* (2005)** investigated replacing 10–50% of yellow corn with potato by-product meal (PBM) in common carp diets. They reported that a 50% replacement level significantly reduced body weight (BW), weight gain (WG), and SGR.

Ghazalah *et al*. (2002) also showed that replacing 25% or 50% of yellow corn with PBM had no significant effect on BW, WG, and SGR in Nile tilapia.

Furthermore, **Shouqi *et al*. (1997)** found that increasing dietary potato protein concentrate from 0 to 51% in the rainbow trout (*Oncorhynchus mykiss*) diets significantly reduced final BW and SGR and increased mortality. **Saleh (2001)** demonstrated that yellow corn could be replaced by up to 50% PBM or 25% date stone meal (DSM) in the Nile tilapia diets without negatively impacting growth performance or feed utilization.

Additionally, **Ufodike and Matty (1988)** fed the rainbow trout *(Salmo gairdneri)* diets containing 10, 20, and 30% corn or potato waste. They concluded that increased inclusion of these ingredients improved weight gain, SGR, protein efficiency ratio (PER), and apparent net protein utilization (NPU).

Degani *et al.* (1986) observed that potato starch had less effect on growth than wheat meal, bread meal, or soluble corn starch in the European eels. Finally, **Omoregie *et al*. (2009)** also reported that sweet potato peel (SPP) inclusion at 0, 5, 10, 15, 20, and 25% in isonitrogenous (31.22% CP) diets for the Nile tilapia revealed that the highest body weight gain occurred at 5% SPP, while the lowest was recorded at 25% SPP inclusion.

Feed intake (FI) and crude protein intake (CPI) values were significantly ($P< 0.05$) increased with increasing the levels of sun-dried discarded potato (SDDP) inclusion in the Nile tilapia diets. Meanwhile, both feed conversion ratio (FCR) and protein efficiency ratio (PER) showed insignificant ($P> 0.05$) improvement.

These findings are consistent with those of **Abd El-Hakim e*t al.* (2010)**, who fed the mono-sex Nile tilapia *(Oreochromis niloticus)* diets containing culled inedible sweet potato root (CSP) as a non-traditional energy source replacing yellow corn energy at 0, 25, 50, and 100% (CSP0, CSP25, CSP50, CSP100). They reported that the inclusion of CSP at 50 and 100% led to similar, non-significant FCR values compared to the control group, yet both levels significantly improved PER compared to the 25% replacement level. Additionally, CSP inclusion had no significant effect on energy utilization.

Similarly, **Olukunle (2006)** assessed the use of sweet potato peel meal as a cost-effective substitute for maize in African catfish *(Clarias gariepinus)* diets at 0%, 25%, 50%, and 75%. He found that fish tolerated low concentrations well, but feed utilization decreased as the level of sweet potato peel meal increased. The highest feed conversion efficiency (FCE) and PER were recorded at the 25% inclusion level compared to 50 and 75%.

In a related study, **Soltan *et al.* (2005)** found that replacing yellow corn with 50% potato by-product meal (PBM) in common carp diets significantly improved FCR and PER, more than higher or lower inclusion levels. **Saleh (2001)** also reported that yellow corn energy could be safely replaced with 25% date stone meal (DSM) or up to 50% PBM in the Nile tilapia diets, without negative effects on nutrient utilization.

Omoregie *et al.* (2009) introduced sweet potato peel (SPP) at 0, 5, 10, 15, 20, and 25% in the Nile tilapia diets. They found PER values of 2.14, 1.88, 1.59, 1.70, 1.45, and 1.13 and apparent net protein utilization (ANPU) values of 27.14, 33.55, 30.42, 23.24, 31.79, and 14.04, respectively. The best FCR values (1.49 and 1.71) were recorded in the control and SPP5 groups, while the SPP20 and SPP25 groups showed significantly poorer FCR values.

Regarding blood parameters, incorporation of SDDP in fish diets had a significant (P< 0.05) effect on most blood indices, except for the albumin: globulin ratio, creatinine, cholesterol, triglycerides, and bilirubin, which were not significantly (P> 0.05) affected. Fish fed diets containing 45% SDDP (D4) showed the highest values of total protein, albumin, globulin, glucose, AST, ALT, uric acid, amylase, and trypsin compared to the control group (D1). Fish fed the 30% SDDP diet (D3) recorded the highest albumin: globulin ratio and bilirubin levels but the lowest values of globulin, triglycerides, amylase, and trypsin. On the other hand, fish receiving the 15% SDDP diet (D2) had the highest cholesterol and triglyceride values among all groups.

Biochemical parameters serve as essential tools for evaluating fish health and the effects of dietary supplements, as reported by **Authman *et al*. (2021)**. Blood is widely recognized as a reliable indicator of health status **(Joshi *et al.*, 2002)** and functions as a pathological marker for the entire organism **(Omitoyin, 2006)**. Hematological parameters are thus crucial for diagnosing physiological changes in fish exposed to environmental or dietary stressors. **Raiza-Paiva *et al*. (2000)** emphasized the importance of establishing reference hematological values for fish species, as deviations often signal physiological disturbances. **Oludayo (2010)** observed that in *Clarias gariepinus*, variations in mean corpuscular volume (MCV) and white blood cell (WBC) counts occurred among treatments, although red blood cells (RBC), hemoglobin (Hb), packed cell volume (PCV), mean corpuscular hemoglobin concentration (MCHC), and total protein were not significantly (P> 0.05) affected.

The Nile tilapia fed diets containing sun-dried discarded potato (SDDP) exhibited significant (P< 0.05) increases in body composition components, including organic matter (OM), crude protein (CP), and gross energy content. Conversely, values of moisture, ether extract (EE), and ash significantly (P< 0.05) decreased compared to the control group.

These results are partially in agreement with findings reported by **Abd El-Hakim *et al*. (2010)**, who fed the growing mono-sex Nile tilapia (*Oreochromis niloticus*) diets containing culled inedible sweet potato root (CSP) as a non-traditional energy source replacing yellow corn at 0, 25, 50, and 100% (CSP0, CSP25, CSP50, CSP100). They observed no significant effects on whole-body chemical composition across all treatments.

Similarly, **Soltan *et al.* (2005)** found that replacing yellow corn with potato by-product meal (PBM) in the common carp diets at 0, 10, 20, 30, 40, and 50% had no significant effect on whole-body moisture content. However, the highest replacement level (50%) significantly reduced protein content and increased ash content. Moreover, all levels of PBM substitution significantly reduced body fat content compared to the control.

Soltan (2002) reported that increasing PBM levels up to 50% in tilapia diets did not significantly affect body protein content, whereas higher inclusion levels (60, 70, or 80%) significantly decreased protein and ash contents.

These results agree with **Shouqi *et al*. (1997)**, who reported that the CP content of the rainbow trout *(Oncorhynchus mykiss)* decreased significantly ($P< 0.05$) as dietary potato protein concentrate increased from 0 to 51%. Similarly, **Xie and Jokumsen (1997)** observed that potato protein concentrate inclusion significantly increased ash content in the rainbow trout.

Olukunle (2006) found no significant changes in the carcass composition of the African catfish *(Clarias gariepinus)* when maize was replaced by sweet potato peel (SPP) meal at levels of 0, 25, 50, and 75%.

Likewise, **Omoregie *et al.* (2009)** assessed the effect of replacing yellow corn with SPP at 0, 5, 10, 15, 20, and 25% in the iso-nitrogenous Nile tilapia diets (31.23% protein) over a 10-week feeding period. They found that fish fed 25% SPP had the lowest protein content, significantly different from the other groups, except SPP15. Ash content remained relatively constant across all treatments. Additionally, the control group (SPP0) exhibited the highest lipid content, which was significantly different from the other treatments.

Faramarzi *et al*. (2012) conducted a similar experiment on the common carp *(Cyprinus carpio*), incorporating SPP at 0, 5, 10, 15, 20, and 25%. The fish fed SPP25 had the lowest protein content, significantly different from other treatments, except SPP15. Again, ash levels remained statistically unchanged among groups, while the highest lipid content was observed in the control (SPP0) group.

Regarding energy and protein utilization, the inclusion of SDDP at different levels in the Nile tilapia diets resulted in an insignificant ($P> 0.05$) increase in energy retention percentage (ER%) compared to the control (D1). The recorded improvements in ER% were 18.79%, 39.99%, and 42.75% for the D2, D3, and D4 groups, respectively, relative to the control. Moreover, protein productive value (PPV%) significantly ($P<0.05$) increased by 22.52, 45.87, and 53.18% in the D2, D3, and D4 groups, respectively.

Abo-State *et al*. (2021) reported significant ($P< 0.05$) differences in ER and PPV among the Nile tilapia groups supplemented with mannan oligosaccharide (MOS) and β-glucan at 2, 4, and 6g/ kg. The highest values were observed in fish fed 2 and 4g/ kg. However, they found no significant differences ($P> 0.05$) among the tested levels of MOS and β-glucan on ER and PPV.

In a more recent study, **Abozaid *et al*. (2024)** observed that supplementing the Nile tilapia diets with *Saccharomyces cerevisiae* at 4, 8, and 12g/ kg significantly (P< 0.05) decreased ER% but significantly (P< 0.05) increased PPV%.

The incorporation of sun-dried discarded potatoes (SDDP) into the Nile tilapia diets significantly reduced feed formulation costs. The cost per kilogram of diet decreased from 20.315 LE in the control diet (D1) to 19.490, 18.665, and 17.840 LE for diets D2, D3, and D4, respectively. Furthermore, the net economic improvement was 13.39, 24.01, and 23.85% for D2, D3, and D4, respectively, compared to the control group fed the SDDP-free diet.

Goda *et al.* (2012) emphasized that the rising cost of feed is among the key factors limiting profitability in aquaculture. Their study indicated that diets containing 1g *Saccharomyces cerevisiae* per 100g diet were the most cost-effective for the Nile tilapia fingerlings. Similarly, **Tharwat (1999)** reported that production costs were influenced by the feed conversion ratio and the price per ton of each experimental diet, with the control diet leading to the highest cost per ton of fish gain.

On the other hand, **Azevedo *et al*. (2015)** explained that economic efficiency encompasses technical, productive, and price efficiencies, with overall efficiency resulting from the interaction of the latter two. **Aderolu *et al*. (2011)** demonstrated significant (P< 0.05) differences in feed costs and fish value when yellow corn was replaced by biscuit waste at 0, 50, 75, and 100%.

Olomu (1995) stated that increased feed costs per kilogram of weight gain are often due to elevated feed intake. **Zahari and Alimon (2006)** proposed that alternative, non-competitive, and low-cost ingredients can partially substitute conventional protein and energy sources in aquafeed formulations. **Abareethan and Amsath (2015)** also reported that probiotic use could reduce feed costs, supporting the practicality of alternative diet formulations.

Abd El-Hakim *et al*. (2010) evaluated culled inedible sweet potato roots (CSP) as a non-traditional energy source in the Nile tilapia diets, replacing yellow corn at 0, 25, 50, and 100%. Their results showed that CSP at 50 and 100% reduced the cost per kilogram of weight gain by 4.67 and 1.24%, respectively, compared to the control, while CSP at 25% increased it by 5.72%.

Olukunle (2006) replaced maize with sweet potato peel (SPP) meal at 0, 25, 50, and 75% in *Clarias gariepinus* diets and found that SPP-based diets were less expensive than the control and helped reduce weight gain costs while maintaining high yield.

Soltan *et al*. (2005) used potato by-product meal (PBM) as a replacement for yellow corn in the common carp diets at 10, 20, 30, 40, and 50%. They found that feed cost per kilogram of weight gain decreased to 83.47, 89.07, 87.47, 77.60, and 86.40% of the control, respectively, indicating cost-effective substitution at these inclusion levels.

Saleh (2001) similarly noted that replacing yellow corn with PBM in the Nile tilapia diets at 25 and 50% lowered feed costs per kilogram gain by 1.35 and 6.22%, respectively. However, a 75% replacement level increased feed costs by 1.08% compared to the control.

El-Garhy (2003) incorporated potato by-products (PB), macaroni by-product waste (MP), or their combination (50% PB + 50% MP) to replace 25 or 50% of yellow corn energy in tilapia diets. He reported reductions in feed costs of 7.35, 5.39, and 3.43%, respectively, compared to the yellow corn-based control diet, attributing the cost reduction to the lower market prices of PB and MP. Additionally, feed cost reductions per kilogram of weight gain were 23.11, 19.92, and 19.52% for the PB, PB + MP, and MP groups, respectively, relative to the control.

Soltan (2002) concluded that replacing yellow corn with PBM up to 40% reduced feed costs per kilogram of weight gain. However, higher replacement levels (50–80%) were not economically viable. At the 40% inclusion level, feed costs were reduced by 7.53%.

CONCLUSION

Based on the obtained results, it can be concluded that under the conditions available during the present study, incorporating sun-dried discarded potatoes (SDDP) as an alternative energy source to yellow corn—the primary conventional energy source in fish feed formulation—proved effective. The inclusion of SDDP led to notable improvements in growth performance, feed utilization, and feed conversion ratio, without any adverse effects on blood parameters. Additionally, the crude protein content of the fish body increased, along with enhanced values of energy retention (%) and protein productive value (PPV%). Feed formulation costs were significantly reduced, resulting in improved net economic efficiency. Furthermore, replacing yellow corn with SDDP at levels up to 45%—equivalent to 100% of the yellow corn content in the control diet—had no negative impact on fish health, indicating the potential of SDDP as a cost-effective and safe ingredient in the Nile tilapia diets.

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