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SCIENTIFIC PAPER

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CIRCULAR ECONOMY IN APPLE PROCESSING INDUSTRY: BIODIESEL PRODUCTION FROM WASTE APPLE SEEDS

Article Highlights

- Apple seeds landfilling increases terrestrial acidity
- Valorization of apple seeds for the circular economy
- Simulation, economic and environmental models were created
- The lowest biodiesel price was 0.39 US$/kg
- Biodiesel production from apple seeds can be environmentally friendly

Abstract

Apple pomace is a solid waste derived from the apple processing industry. To foster sustainability, the apple processing industry must implement the circular economy model of biorefinery and treat apple pomace as a valuable source of apple seed oil. For the first time, this study dealt with the design, economic, and potential environmental impact assessment of biodiesel production from apple seed oil obtained from apple pomace. An Aspen Plus® and WAR® software were used to evaluate the designed biodiesel production. The main production steps were the supercritical CO_2 extraction, the methanolysis of apple seed oil, the methanol recovery, and the biodiesel separation. The production facility was assumed to process 24 tons of apple seeds daily. The total capital and production costs were 1.26 US$ million and 2.82 US$ million, respectively. If revenues from selling apple seed meal as cattle feed were included, a biodiesel price could be 0.39 US$/kg. The process was environmentally friendly when apple seed meal was not treated as waste.

Keywords: apple seeds, Aspen Plus®, biodiesel; economics, supercritical technology, WAR®.

Modern industrial development is toward implementing the circular economy model to foster sustainability. Thus, all industrial waste should be used as the source of value-added products. However, industrial food waste produced in large amounts generates a significant loss of valuable materials and raises serious management problems. Nevertheless, fruits have the highest wastage rates of any food. The apple processing industry generates yearly around 8 million tons of waste apple pomace [1,2]. So far, apple pomace has been used in the production of protein-enriched feed [3], pectin [4], citric acid [5], biopolymer polyhydroxyalkanoates [6], charcoal [7], biogas [8], ethanol [9], and acetone-butanol-ethanol [10] among others. Economically, the best technique to reuse apple pomace is yet to be shown. Vinegar production is a widely practiced way to utilize pomace from a facility engaged in apple processing. However, apple seeds in apple pomace of 2%-4% [2] can cause a bitter taste of vinegar due to hydrogen cyanide formed during the long fermentation process. Therefore, the industry prefers to remove the waste apple seeds, whose landfilling can cause severe human air to breathe problems and disturb terrestrial ecosystems.

On the other hand, apple seeds are a good source of oil and are obtained by sieving and separating from apple pomace [11]. The apple seed oil content varies in the range of 15-29.4% [12], which is similar to the soybean seed oil content (about 20%) but lower than the sunflower seed oil content (about 40%) [13]. Apple seed

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oil is declared edible [14-16], but it would be hard to achieve market success like sunflower or soybean oil due to humans' difficulties to change acquired taste habits. Besides that, more information is needed on the metabolic effect of apple seed oil in humans [17,18]. Apple seed oil is already used in cosmetic industries in various products [19]. However, little is known about the waste generated in the cosmetic industry and its impact on the environment.

Biodiesel is a green alternative to fossil-derived diesel. However, feedstock production and its conversion to biodiesel can emit more greenhouse gases than fossil fuels [20]. Various feedstocks have been tested to overcome this problem. There have been several studies about the economic and environmental analysis of biodiesel production from waste biomass. However, most simulation studies of biodiesel production have focused only on waste cooking [21,22] and nonedible oils [23,24], chicken fat [25], tallow [26], and microalgae [27]. Since recently, the waste of the fruit processing industry has attracted scientists investigating biodiesel production. Valorization of fruit waste, as low-cost oily feedstocks, fits in the scope of cheap and clean biodiesel production technologies. Grape [28] and apple pomace [29,30] are promising feedstocks for biodiesel production. Although there have been several studies about custard apple waste for biodiesel production [31,32], the production is limited to tropical countries. Except for grape pomace, no previous work has included an economic evaluation or a biodiesel refinery environmental impact assessment. In addition, a recently published paper points out the lack of profound research studies with techno-economic analysis, life-cycle assessment, and inter-sectoral initiatives of apple processing-derived waste [33]. Therefore, this study improves apple waste processing compared to landfill disposal, combustion for energy, or implementation in cosmetic industries.

MATERIALS AND METHODS

Background

Process design and simulation basis

This paper provides an innovative conceptual process design for converting waste apple seeds to biodiesel using the Aspen Plus® v8.6 software computer simulation to obtain the consistent process flowsheet, mass and energy balances, equipment sizing, and the involved process costs. The process design and simulation involve creating a process flowsheet (setting up the unit models, operational conditions, and reaction) and defining chemical components and thermodynamics.

Experimental studies supporting the model

Figure 1 shows a block diagram for manufacturing biodiesel from apple seeds originating from waste apple pomace. Additional pretreatment steps of apple pomace (drying and deseeding) are not considered for process design because fruit processing companies perform apple pomace deseeding. Besides, many research studies have reported that they obtained apple seeds from local fruit processing companies [16,19,34,35].

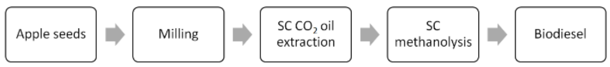


Figure 1. Block diagram of biodiesel production from apple seeds.

Apple seeds were first milled to reduce the size of seed particles and then submitted to oil extraction. So far, the oil has been extracted from apple seeds with petroleum ether [15], *n*-hexane [16,36], and supercritical (SC) CO_2 [34,35]. Linoleic acid is a predominantly fatty acid of apple oil regardless of the used technique from oil recovery. Therefore, the oil may be considered a suitable feedstock for biodiesel production if the ratio of polyunsaturated fatty acid content and the sum of saturated and monounsaturated fatty acid contents, ∑PUFA/(∑SFA + ∑MUFA), is close to one or below. However, the cold filter plugging point (CFPP) has a low value [36]. Generally, apple seed oil obtained using solvents show better potential as biodiesel feedstocks. However, solvents are of fossil origin, so their replacement is strongly recommended. Furthermore, among the SC techniques, the empirical cold filter plugging point (CFPP) of apple seed oil obtained with the ultra-high SC extraction system (- 7.5 °C) was lower than that (4.5 °C) conducted in the pressure range of 100-450 bar. Still, processing at ultra-high SC pressures may not be cost-competitive and safe. For the reasons above, the present study has been conceived to simulate the SC-CO_2 extraction of oil from apple seeds below 30 MPa. The data on the SC extraction unit conditions were based on the experimental values [34].

The extracted oil was then subjected to alcoholysis. Biodiesel production processes based on homo- or heterogeneously-catalyzed alcoholysis were not considered since the operation parameters of the oil pretreatment and the implemented catalyst have not been validated against any experimental research. However, SC simulation was relied on just one assumption - operating conditions. SC methanolysis has neither been experimentally verified. Moreover, the lab- or pilot-scale research about apple waste for biodiesel production is currently quite limited. However, simulation results will be reliable and accurate since process simulation used in this study was classified into design mode, which means that some level of equipment performance was assumed for equipment designs to meet this performance. In this way, simulation helps to avoid the cost of building a pilot and industrial plant. The reactor equilibrium (REquil) model was used to simulate the reactor for the SC methanolysis. This reactor model performs the chemical and phase equilibrium simultaneously using only the reaction stoichiometric. With the REquil model, biodiesel yield can be predicted only using the methanolysis stoichiometry and the SC operating conditions. The standard SC oil methanolysis conditions (350 °C, 20 MPa, and oil-to-methanol molar ratio of 1:42) are implemented [37,38]. The post-treatment stage of methanol recovery and biodiesel separation was briefly examined, too.

Models of chemical components and physical properties

The simulation model components were apple seeds, trilinolein (considered apple seed oil), methanol, methyl linoleate (biodiesel), glycerol, and CO_2. All chemical species were available in the Aspen Plus® component database except for apple seeds. The usage of seeds as modeling components for simulation purposes is rare. The thermodynamic properties of seeds are unknown and are defined as nonconventional solids with a particle size distribution.

The Peng-Robinson state equitation was selected as a general thermodynamic model because it is an industry-standard for calculating solid-vapor and solid-liquid equilibrium [39]. Simultaneously, UNIFAC and UNIQUAQ were used in thermodynamic calculations for the process units involving apple seeds, oil, and CO_2.

Economics basis

Process equipment sizing and capital cost estimating were conducted through vendor quotes and estimations for the 1st quarter of 1994, from Aspen Economic Analyzer® v8.6 software. The apple seed facility was a grass-root located in North America. The facility lifetime was set at 8760 h/year (assuming 365 operating days/year). The biorefinery would be located on soft-clay soil. It would promote a new, slightly complex process with digital process control and an ASME pressure vessel design code. The possible contingency was 18%. The facility operation and maintenance labor were set as three shifts per day. Operator and supervisor labor unit costs were 29 US$/h and 44 US$/h, respectively [40]. It was assumed that three operators and one supervisor could maintain continuous work of the process per shift. The estimated start date of basic engineering was 2022/03/15. The costing basis (US$) and investment parameters are summarized in Table 1.

Table 1. Costing basis for economic analysis

Specifications of investment parameters	
The economic life of the project	25 years
Tax rate	30%/year
The desired rate of return/Interest rate	20%/year
Salvage value	20% of initial capital cost
Depreciation method	Straight line
Project capital escalation	5%/year
Products escalation	5%/year
Raw material escalation	3.5%/year
Operating and maintenance labor escalation	3%/year
Utility escalation	3%/year
Working capital percentage	5%/year
Operating supplies	10% of maintenance/year
Laboratory charges	25% operating labor/year
Facility overhead	50% of operating labor and maintenance costs/year
G&A expenses	8% of subtotal operating costs/year
Facility type	Chemical processing facility
Operating mode	Continuous processing
Length of the start-up period	20 weeks
Process fluids	Liquids, gases, and solids
Prices of chemicals (US$/kg)	
Apple seeds	0.000[a]
Methanol	0.267
CO_2	0.0059
Biodiesel	≤0.970
Apple seed meal	0.260
Wastewater treatment	0.091
Prices of utility (US$/MJ)	
Fired heat (1000 °C)	3.5
High pressure (HP) steam	2.5
Low pressure (LP) steam	2.2
Refrigerante (Propane)	21.2
Electricity	0.0775[b]

[a]Apple waste currently is without value in the market; [b]US$/kWh.

This study considered the zero feedstock price since apple seeds were a waste (Table 1). The costs of drying apple pomace and separating the seeds might be included in the biorefinery feedstock price, depending on the applied apple processing industry technology. The transport cost should be neglected because the biorefinery would be close to the apple processing facility. The trading CO_2 price of 0.0059 US$/kg was used to promote emissions trading systems. The price of fossil diesel on the global market ranges from 0.97 US$/kg to 1.88 US$/kg [41], so the price of biodiesel must be lower. Defatted apple seed meal can be used to enrich wheat bread [42], as cattle feed [16,43], or incorporated in the chewing gum system [44]. In this study, apple seed meal was considered as cattle feed.

Environmental impact assessment basis

The PEIs of the biodiesel production processes from apple seeds were assessed with the waste reduction algorithm (WAR® v.1.0.17, United States Environmental Protection Agency, Washington, DC, USA). WAR® is a tool for rapid analysis of a product's life cycle during the conceptual and design stages. Total PEI was calculated as the sum of eight PEIs categories: human toxicity potential by ingestion (HTPI), human toxicity potential by dermal and inhalation exposure (HTPE), terrestrial toxicity potential (TTP), aquatic toxicity potential (ATP), global warming potential (GWP), ozone depletion potential (ODP), photochemical oxidation potential (PCOP), and acidification potential (AP). The lower PEI, the environmental friendliness process is. Each component in the process stream contributes to each category through the mass flow rate and chemical potency. Category scores were normalized, and their weighting factors were set to 1.0 to eliminate bias in the PEI calculation. Energy balance data must also be specified to evaluate the energy consumption rate from fossil sources. In the present study, processes were assumed to be natural gas-based.

RESULTS AND DISCUSSION

Process design

The flowsheet and main streams table of the biodiesel production from apple seed is presented in Figure 2. The process consists of the following steps: SC-CO_2 oil extraction, SC biodiesel production, methanol recovery, and biodiesel separation. First, the apple seeds were crushed (CRUSHER). The particle size distribution of the obtained apple seed powder was taken from elsewhere [34].

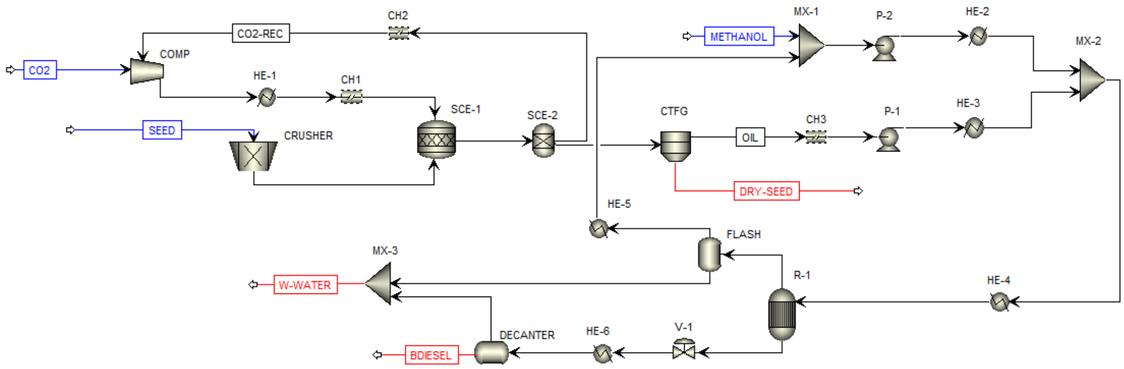
Then, CO_2 previously compressed (COMP) at 24 MPa and heated (HX-1) at 40 °C, combined with the recycled CO_2, was used to SC extract the oil from the apple seed powder (SCE-1/SCE-2). The oil was removed from the residual seed meal by centrifugation (CTFG). Next, apple seed oil and methanol were transferred to the SC methanolysis reactor (R-1). Both methanol and oil were pressurized (P-1 and P-2) and heated (HX-2, HX-3, and HX-4) before the methanolysis stage (20 MPa, 350 °C).

A standard molar ratio (42:1) of methanol and apple seed oil was used. Methanol was recovered using a flash distillation unit (FLASH), colled (HX-5), and recycled. The residual reaction mixture was first depressurized (V-1) and cooled (HX-6), and then the methanol/glycerol mixture was separated from the biodiesel phase by a gravitational decanter (DECANTER). Thermodynamic calculations determined the simulated biodiesel product specifications (Table 2) in Aspen Plus®.

The European biodiesel standards (EN 14214) were not met in simulated specifications, except for the density and cetane number (Table 2). However, significantly better physicochemical properties were reported [36]. This inconsistency resulted from the difference in assumptions adopted for biodiesel composition. The simulated biodiesel was presented as methyl linoleate, while its physicochemical properties were calculated empirically. Moreover, empirically calculated biodiesel values were based on the mean values of fatty acid methyl esters determined for apple seed oil samples extracted using *n*-hexane. Thus, more studies were needed to specification apple seed oil obtained from other extraction techniques (*i.e.*, SC extraction).

Cost estimation

Figure 3 shows the fixed capital and production costs distribution for apple seed oil-based biodiesel production. As shown in Figure 3a, the oil extraction facility was the most expensive, contributing 47% of the total fixed capital cost. The utility costs were the highest fraction of the total production costs (Figure 3b). The most cost-impacting factors were electricity and LP steam. The oil extraction unit consumed electricity significantly, while the biodiesel production unit spent LP steam. A heuristic (discovery) model was used for the techno-economic analyses, and therefore the heat integration was not implemented here. The contributions of raw material were found to be negligible. The results showed that raw material costs derived only on methanol costs; the apple seeds as waste were priceless while CO_2 was recycled. Several other SC biodiesel processes have higher raw material costs due to the higher price of the employed oily feedstock [48-50]. The annual capital costs were 2.82 US$ million, which were significantly lower than the capital cost of Jatropha and waste canola of ~32 US$ million [48,49] or waste frying oil of 35 US$ million [51]. However, the reported studies were related to a higher biodiesel annual capacity of 40000 tons. Also, these



	SEED	CO2-REC	METHANOL	OIL	DRY-SEED	W-WATER	BDIESEL
Temperature, °C	25	-76	25	20	20	37	20
Pressure, kPa	101.3	200	101.3	101.3	101.3	70	101.3
Mass flow, kg/h	1000	8500	55	208	792	53	210
Vapor fraction	0	0	0	0	0	0	0
Liquid fraction	0	1	1	1	0	1	1
Solid fraction	1	0	0	0	1	0	0
Density, kg/m³	555	1236.6	792.9	924.8	555	961.1	887.6
Component mass fraction							
SEEDS	0.79	0.00	0.00	0.00	0.998	0.00	0.00
CO_2	0.00	1.00	0.00	0.00	0.000	0.00	0.00
OIL	0.21	0.00	0.00	1.00	0.002	trace	trace
WATER	0.00	0.00	0.00	0.00	0.000	0.00	0.00
METHANOL	0.00	0.00	1.00	0.00	0.000	0.48	0.03
GLYCEROL	0.00	0.00	0.00	0.00	0.000	0.41	0.00
BIODIESEL	0.00	0.00	0.00	0.00	0.000	0.11	0.97

Figure 2. SC biodiesel production from apple seed.

Table 2. Physicochemical properties of the simulated apple seed oil and biodiesel

	Oil		Biodiesel		
Property	Simulated	Experimental	Simulated	Experimental	EN 14214
Density, kg/m^3	924.9[a]	921.9[a]	891[b]	881[b]	860-900[b]
Viscosity	49.8[c]	-	2.28[d]	4.12[d]	3.5-5.0[d]
Iodine value, g J_2/100 g	-	1.29	-	126.9	≤120
Saponification value, mg KOH/g oil	-	186.5			
Refractive index [a]	1.46	1.47			
Flash point, °C			27.5	-	≥101
(Palmitic acid) C16:0		13.39			
(Stearic acid) C18:0		7.69			
(Oleic acid) C18:1		34.84			
(Linoleic acid) C18:2		63.76			
(Linolenic acid) C18:3		1.61			
(Arachidic acid) C22:0		2.04			
Cetane number			51.4	50.4	≥51
Oxidative stability (110 °C), h			-	4.48	6 min
Reference	This study	[34,16]	This study	[36]	

[a]At 20 °C; [b]at 15 °C; . [c]at 20 °C, mPas; [d]at 40 °C, mm^2/s.

studies evaluated biodiesel production from oil, while the present study included oil extraction.

Concerning reactants used in this process, little waste was generated. Wastewaters (W-WATER) were sent to the treatment facility, while the residual apple seed meal (DRY-SEED) could be discharged in the field as fertilizer or used as cattle feed. Considerable amounts of protein, fiber, and toxigenic amygdalin (source of cyanide anions) can be found in apple seed residues [43]. Amygdalin is the glucoside occurring in apple seeds at contents of approximately 0.2% [45]. During the processing, releases of cyanide from apple seeds amygdalin to the environment (0.06 g/g of theoretical yield) may occur [46]. While the nutritional value of apple seed meal protein is low, clinical studies regarding the toxic doses of amygdalin have been conducted only with rats and mice. Amygdalin at a moderate dose can increase protein digestibility in rats [43] and improve oxidative balance in mice [47]. However, little is known about the therapeutic doses of apple seed meal in animals, and therefore its use as a cattle feed has not been revealed and waits for its official approval.

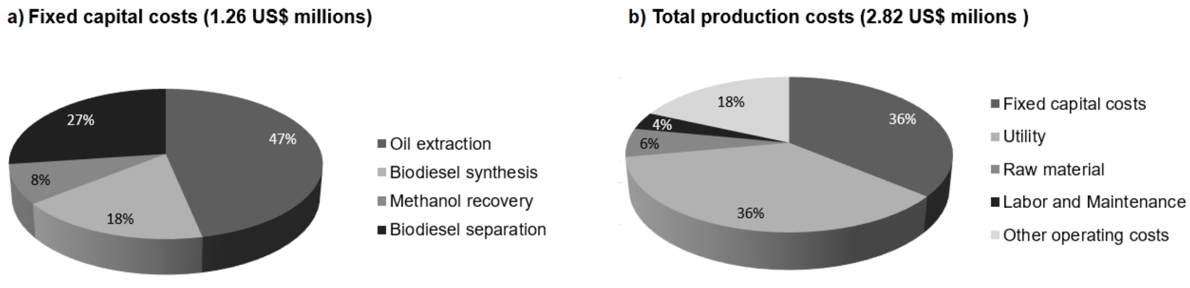


Figure 3. Distribution of (a) fixed capital and (b) total production costs.

Profitability analysis

A biodiesel production cost of 0.96 US$/kg was calculated based on the total annual production cost (2.82 US$ million) and the produced biodiesel capacity (1840 tons/year). The wastewater was considered as a cost, while biodiesel brought revenues. In this study, the revenues from the sale of apple seed meal as cattle feed were also considered. The annual selling revenue was 1.72 US$ million and 3.53 US$ million for biodiesel (0.96 US$/kg) and biodiesel/apple seed meal sales, respectively. Table 3 shows the profitability measures for the SC biodiesel processes from several oily feedstocks. The NPV of the apple seed facility was positive and higher than those of the other two oily feedstocks. Several investigators [23,52,38] have designed facilities with a higher annual capacity (8000 tons of biodiesel) than the facility considered in the present study for the same feedstock mass flow because the previous studies were based on the oil mass flow and the present study on the seed mass flow. Therefore, the capacity of the facility based on apple seed was increased by 440% and 810% to produce 8000 and 30000 tons/year of biodiesel, respectively, and compared to those based on castor and waste canola oil (Table 3). With increasing the facility capacity, NPVs increased while the payback period decreased. This trend was significant when the revenues from the sale of apple seed meal were included in analyzing the facility's profitability.

Food waste biorefineries have a higher (25 years) lifetime period [40]. Positive ROI (return of investment) and payback period below 15 years make the food waste biorefinery attractive for investment [40]. With a payback period of 8 years (Table 3), the apple seed-based biodiesel facility was considered economically profitable.

Table 3. The profitability measures of a biodiesel facility

	This study						Castor oil [24]	Waste canola oil [49]
Revenues	Biodiesel			Biodiesel & Apple seed meal			Biodiesel & Glycerol	
Annual facility capacity, tons	1840	8000	30000	1840	8000	30000	8000	30000
NPV, US$ millions	1.99	35.8	152	5.36	46.9	164	4.16	21.07
ROI, %	12.58	94.3	128.2	55.9	-	-	20	23.81
Payback period, year	7.95	1.06	0.78	1.79	0	0	5.00	4.2

Sensitivity analysis

Sensitivity analyses were conducted to investigate the sensitivity of the NPVs and payback period to changes in a variety of parameters. Two parameters were studied over 25 years. The apple seed and biodiesel prices varied by ±10, 20, 30, and 40% from the original values shown in Table 4.

Table 4. Sensitivity analysis on a biodiesel production cost

	-40%	-30%	-20%	-10%	Base case	10%	20%	30%	40%
Apple seed, US$/kg	-	-	-	-	0	0.10	0.20	0.30	0.40
Biodiesel, US$/kg	0.58	0.68	0.77	0.87	0.96	1.08	1.21	1.38	1.62

Any increase in the price of apple seeds, at a selling price of biodiesel of 0.96 US$/kg, would lead to the unprofitability of the facility. However, for a biodiesel price of 1.38 US$/kg, the apple seeds price could increase by 10% (the NVP of 1.28 US$ million and the payback period of 12.6 years). Therefore, a further increase in the apple seed price would lead to economic unfeasibility. On the other hand, biodiesel price could be decreased to 0.87 US$/kg, without costs for apple seeds (Figure 4a). The best scenario, not considered in this study, is that price of waste is negative because it imposes several environmental problems; therefore, removing them from the environment incurred negative costs. In that case, the final biodiesel cost will again reduce.

However, if apple seed meal were included as revenue, biodiesel price could be decreased to 0.39 US$/kg with an increase in apple seed price by 10% (Figure 4b). The suggested biodiesel production facility was profitable since the payback period varied from 2 to 12 years. However, this process could be, in the future, highly dependent on the apple seed price.

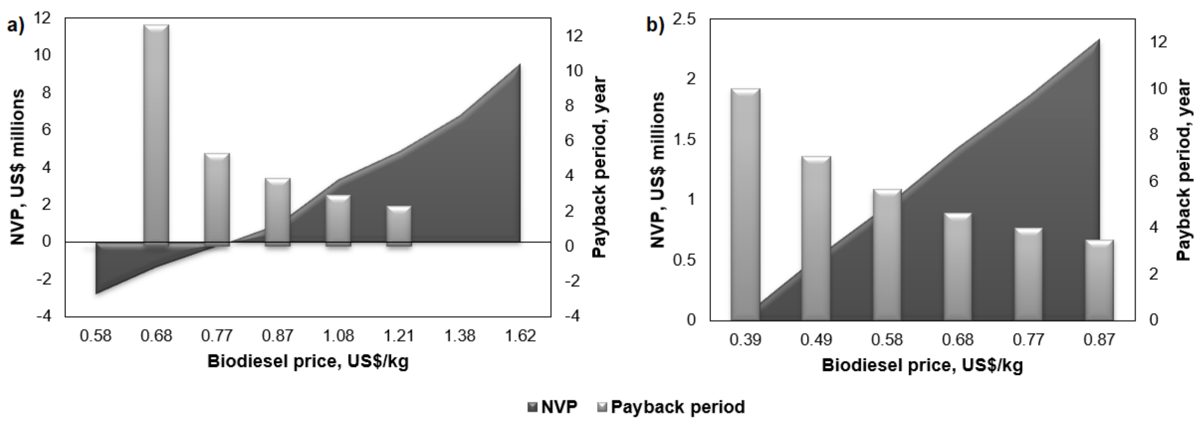


Figure 4. Influence of biodiesel price on process profitability.

Retail diesel prices were 0.97 US$/kg to 1.88 US$/kg [41], which means that biodiesel from apple seed (0.39 US$/kg to 1.21 US$/kg) was comparative to commercial diesel. Biodiesel price was in the range from 0.5 US$/kg for waste cooking oil [53] to 2.0 US$/kg for palm oil [54], depending on the production technology. Generally, SC technologies have a biodiesel selling price of 0.48 US$/kg [55] to 1.53 US$/kg [56]. The use of whole apple pomace to produce bioethanol was cost-competitive; the reported apple pomace-based bioethanol price in 1996 was 0.20 US$/kg [57].

Environmental impact assessment

A comparative assessment of the PEIs generated within the system, including the energy effect, was investigated to identify the major contributors of biodiesel production from apple seeds to the environmental outcomes. Figure 5 shows that if apple seed meal was used as cattle feed, PEI of the process was much lower than the PEI of the process, which treated apple seed meal as waste. The highest contributor to the PEI was AP because of the high content of biodegradable proteins and fibers. The high consumption of fossil fuels could also increase AP. On the other hand, a high PCOP in waste apple seed meal may be explained by the presence of volatile hydrogen cyanide, which may produce photochemical smog.

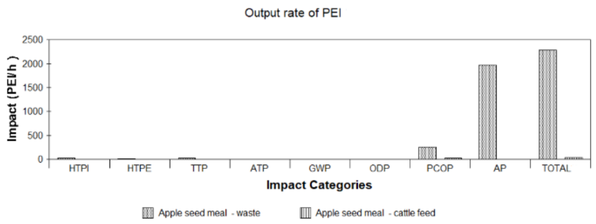


Figure 5. Influence of biodiesel price on process profitability.

The total environmental impact of biodiesel production from apple seeds was 2290 PEI/h and 384 PEI/h, with and without treating apple seed meal as waste. Biodiesel production processes from green seed canola oil and waste vegetable oils show a lower total environmental impact of 27.3 PEI/h [23] and 58.7 PEI/h [58], respectively. Except process using waste vegetable oils and fats [21,22,25,26], low PEIs values of the green seed canola oil process do not reveal it as environmentally friendly because oil extraction is excluded in the analysis. The same situation is with the processes that excluded extraction steps from palm, Jatropha, and microalgae [26]. Furthermore, treating apple seed meal as waste gave positive pollution risks to humans and land, as shown by the HTPI, HTPE, and TTP indexes (Figure 5). These indexes have a mitigation effect on humans and animals.

CONCLUSION

The use of apple seed from waste apple pomace as a biodiesel feedstock is at an early stage of development. Huge worldwide available quantities of apple pomace and less resource-intensive processes (such as the process presented in this study) are promising elements to prove the viability of the food waste biorefinery concept. The main advantages of using apple seeds are that waste apple pomace is a no or low-cost feedstock. Apple seed oil has not been used for biodiesel purposes. So, the present study is an improved way of valorizing apple seeds. The biodiesel price suggested by this study (0.39 US$/kg - 0.96 US$/kg) made this apple seed valorization path a cost-competitive technology. This paper demonstrated that the biodiesel production process from apple seeds was environmentally favorable only if apple seed meal was treated as cattle feed. High energy demand contributed to the high possibilities for acidification, thus indicating the need for heat integration. Also, the experimental-based apple seed biorefinery is still challenging. Furthermore, apple seed meal should wait for an official proof as cattle feed.

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NAUČNI RAD

CIRKULARNA EKONOMIJA U INDUSTRIJI PRERADE JABUKA: PROIZVODNJA BIODIZELA IZ OTPADNIH SEMENA JABUKA

Trop jabuke je čvrsti otpad industrije prerade jabuka. Da bi podstakla održivost, industrija prerade jabuka mora da primeni model cirkularne ekonomije biorafinerije i da tretira trop jabuke kao vredan izvor ulja semena jabuke. Po prvi put, ovo istraživanje se bavilo projektovanjem, ekonomikom i procenom uticaja proizvodnje biodizela iz ulja semena jabuke dobijenog iz tropa jabuke na životnu sredinu. Aspen Plus® i WAR® su softveri, korišćeni za projektovane i procenu proizvodnje biodizela. Glavne proizvodne faze bile su superkritična CO_2 ekstrakcija, metanoliza ulja semena jabuke, regeneracija metanola i separacija biodizela. Predviđeno je da proizvodni pogon prerađuje 24 tone semena jabuke dnevno. Ukupni kapitalni i proizvodni troškovi bili su 1,26 miliona US$ i 2,82 miliona US$, respektivno. Ako bi se uračunali prihodi od prodaje sačme semena jabuke kao stočne hrane, cena biodizela bi mogla biti 0,39 US$/kg. Proces je bio ekološki prihvatljiv kada se sačma semena jabuke nije tretirala kao otpad.

Ključne reči: seme jabuka, Aspen Plus®, biodizel, ekonomija, superkritična tehnologija, WAR®.