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ORIGINAL PAPER

Reshaping Apple Juice Production Into a Zero Discharge Biorefinery Process

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Abstract

In the last decade, the utilization of waste by-product apple pomace has been extensively researched (due to its difficult disposal) and currently finds beneficial usage in various industries; as substrate for microbial growth or recovery of pectin, xyloglucan and polyphenols. In this research apple juice was produced at pilot scale. Furthermore, apple pomace was employed as substrate for the production of pectin, biofuel (pellets) and concentrated apple pomace extract. Extensive mass and heat balances were conducted to evaluate the feasibility of this approach on industrial scale. The produced pellets had very similar characteristics to wood pellets (net calorific value of 20.3 MJ/kg). Dried apple pomace contained 11.9% of pectin. Fed-batch cultivation of baker´s yeast with apple pomace extract demonstrated a potential for partial substitution of molasses in industrial bioprocesses. This concept shows how a zero discharge biorefinery process converts waste from apple juice production into three valuable products enabling connections between different industries.

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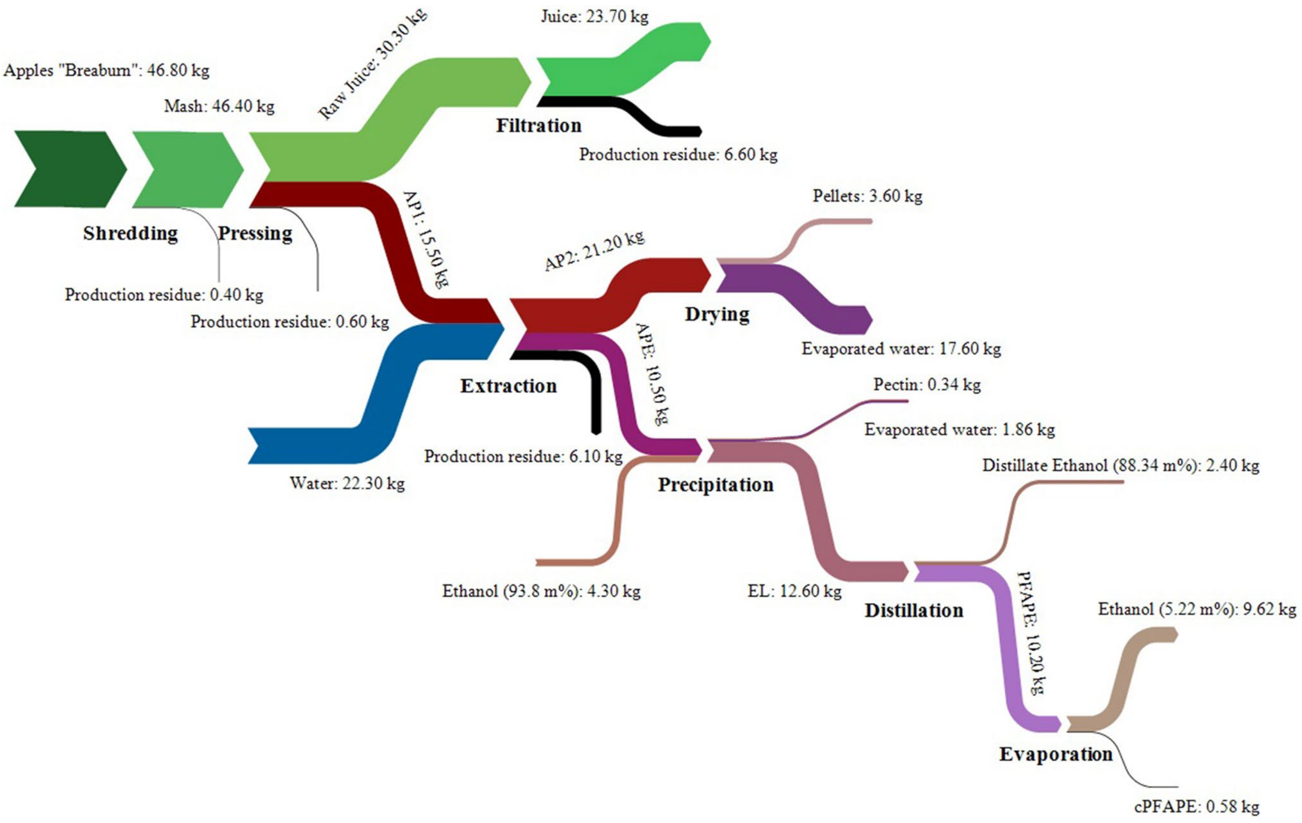
Graphic Abstract



Keywords Apple juice · Apple pomace · Pectin · Pellets · *Saccharomyces cerevisiae*

Statement of Novelty

Apple pomace could be a fully valorised product. A zero discharge biorefinery concept is presented; it generates value added products (Pectin, Feed Stock & Biofuels) out of this stream.

Introduction

Apple is one of the most favoured and consumed fruits by mankind widely grown in temperate regions of the world [1, 2]. Its yearly production in 2016 was 89.33 million tonnes [3]. Most of the fruit is used fresh and around 13% in apple juice manufacture [4]. In 2017 739 thousand tonnes of apple juice was produced in Germany (Fig. 1).

In large scale apple juice production, the raw juice represents 75% of the processed apple mass and the remaining 25% is the by-product, apple pomace [1]. The processing of apples begins with washing and sorting (removal of damaged and diseased fruit). Apples are then grinded by a disintegrator, hammer mill or grating mill. In order to achieve higher yields of juice (break down cell walls), lower the viscosity and reduce pulp slipperiness, commercial macerating enzymes are usually added. The extraction is accomplished through pressing chopped apple continuously (by belt or screw press) or in batches (by hydraulic or bladder press). The produced apple juice is extremely cloudy and contains particles that can be removed by screening. In this case a cylindrical “cider” screen can be used which revolves on a system of rollers. The screen is kept clean by revolving actions causing the pomace to gather into small balls and finally into a continuous roll which falls off the end of the slightly sloping screen. For the “natural” look associated with fresh apple juice, the ground apple pulp is treated with ascorbic acid before pressing to minimize browning. The juice is screened or settled, but not otherwise filtered. Ascorbic acid is added directly to the mill, to be mixed with the pulp after the apples are crushed and pulp exposed to air. If the final product is meant to be cloudy, then the enzyme step is not applied. Otherwise, after juice extraction, the raw apple juice is treated with enzymes to remove suspended solids, which would consequently clog filters, slow the

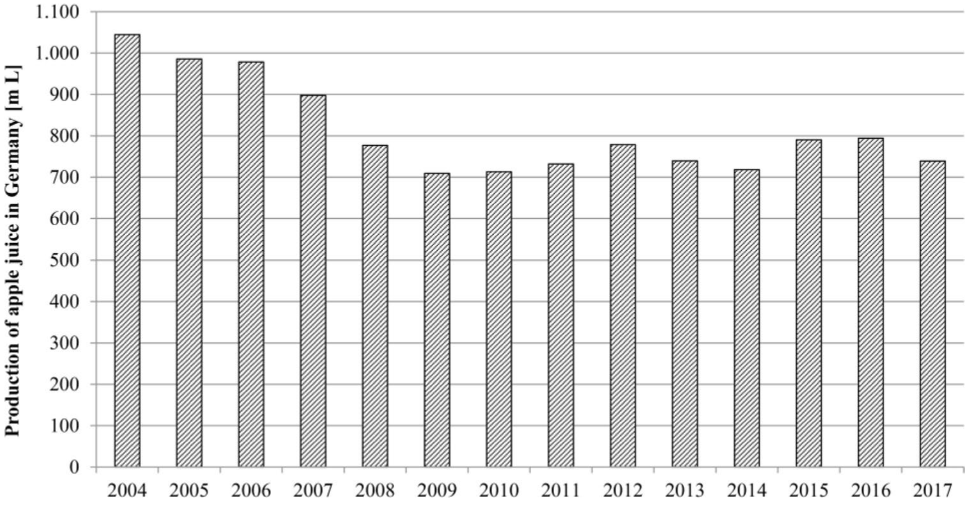


Fig. 1 Production of apple juice in Germany in the years 2004 to 2017 (in millions of L) [5]

production and may cause the juice to form a haze. These enzymes hydrolyse pectin, hemicellulose and other polymers and colloids that increase viscosity of the juice. Enzyme treatment can either be performed as hot method (at 54 °C for one to two hours) or cold method (at room temperature, 20 °C for six to eight hours). Further processing involves heat clarification, fining, filtration and pasteurisation. Basic idea of heat clarification is that heated particles within the apple juice coagulate and are easily removed through filtration. In the fining process, bentonite clay particles absorb tannins and protein-tannin complexes. By filtration large particles, certain proteins and microorganisms are being removed from the apple juice. The final and the most important step for preserving the juice is pasteurisation, which involves heating to a given temperature long enough to destroy all organisms that can develop. Flash pasteurization is rapid heating to near the boiling point (above 88 °C) for 25 to 30 s, in which steam or hot water passes the juice between plates or through narrow tubes that are heated [6].

Considering the large volumes of apple juice being produced, by-product apple pomace is generated worldwide in thousands of tonnes (Table 1). The production of apple pomace in Germany is particularly high (250,000 t/year).

Table 1 Apple pomace generation in some countries worldwide [7]

Country	Quantity (thousands of tonnes)
Brazil	13.75
Germany	250
India	3–5
Iran	97
Japan	160
New Zealand	20
Spain	20
United States	27

Apple pomace is generally composed of skin and flesh (95%), seeds (2% to 4%), and stems (1%). Its composition has been widely explored (Table 2) and differ depending on the variety, origin and processing technology prior to its generation [2].

The disposal of apple pomace into the environment, due to its high bio-chemical oxygen demand, represents a pollution problem. Direct dumping is also difficult, because of the high costs of transportation and the generation of foul smell. In the past, dried apple pomace was used as animal feed, fuel for boilers or added to soil as a conditioner. In the last 30 years its potential has been extensively studied as a substrate for microbial growth and used in the production of value products such as organic acids, enzymes, single cell proteins, low alcoholic drinks, ethanol, biogas, pigment and baker's yeast [13]. Since fresh apple pomace is quite liable to spoil, it must be preserved in order to be stored and used over a long period of time. Preservation can be achieved by drying. Dried apple pomace has demonstrated its worth on animal health and can be utilized for animal feed [14, 15]. It has also been characterized by high pellet-ability [16].

One of the most practical approaches in the utilization of apple pomace is for pectin production [7]. Pectin is a structural linear polysaccharide contained in the primary cell walls of terrestrial plants [17]. Commercial pectin is characterised by high content of galacturonic acid, which has become part of the definition for pectin to be used as food additive or for pharmaceutical purposes. Usual requirements are a minimum of 65% of galacturonic acid on the ash and moisture-free substances [18]. Excellent water binding and gel forming properties even at low concentrations is the main reason to be employed as thickener and stabiliser in the food industry as gelling agent in jams,

Table 2 Examples of physical–chemical composition of apple pomace (expressed in % of dry weight basis) (*TDF* total dietary fibre, *n. d.* not determined)

Composition (%)	References					
	[8]	[9]	[10]	[11]	[12]	[13]
Moisture	3.97–5.4	3.0	3.9–10.8	11.43	7.9	9.0
Ash	1.6	n. d	0.5–6.1	1.8	1.1	1.6
Fat	3.49–3.9	1.5	1.2–3.90	1.53	2.3	2.27
Protein	4.45–5.67	n. d	2.94–5.67	2.74	3.3	2.37
Carbohydrate	48.0–62.0	n. d	48.0–62.0	n. d	n. d	84.76
Starch	n. d	n. d	n. d	n. d	7.8	5.6
Total sugar	n. d	n. d	n. d	n. d	n. d	54.2
Glucose	22.7	6.7	19.5–19.7	12.57	n. d	n. d
Fructose	23.6	19.9	40.3	17.93	n. d	n. d
Saccharose	1.8	11.8	3.8–5.8	7.04	n. d	n. d
TDF	4.7–48.72	55.2	4.7–51.1	43.63	42.1	30.15
Pectin	3.5–14.32	n. d	3.5–14.32	15.27	n. d	7.84

confectionary and bakery fillings, as well as stabilizer in yoghurts and milk drinks. It is also used in the cosmetics, personal care (paints, toothpaste and shampoos) and pharmaceutical industry (gel caps), including new utilization as nutraceutical ingredient. Since the early 2000s, pectin has been recognized to have several beneficial health and nutritional effects as a dietary fibre and prebiotic. Conventional pectin production is generally expensive, requiring extraction factories having a close, large-scale source of raw material (dried citrus peel or apple pomace). In 2015 the average price exceeded 15 $/kg and the market (exceeding 60,000 tons) was close to reach $ 1 billion [19].

The aim of this research was to produce apple juice and to discharge by-product apple pomace by converting it from waste to high value products. In this regard, apple pomace was further processed and generated three products: pectin, pellets and a pectin free apple pomace extract (PFAPE). Pellets of dry apple pomace were examined in order to be employed as a biofuel. Mass and heat balance were discussed. The performance of PFAPE as a molasses supplement in industrial fed-batch fermentation of baker´s yeast *Saccharomyces cerevisiae* was evaluated. The results were used to present a concept for an industrial biorefinery and energy savings. The presented process should be regarded as an approach to turn apple juice production into a zero-discharge process by creating interfaces with new industries.

Materials and Methods

Production of Apple Juice

46.8 kg of Braeburn apples (New Zewaland Apple LTD, Whakatu, New Zealand) were washed and grinded by Shark Fruit 1.6 kW (Vares Mnichovice a.s.; Mnichovice, Czech Republic). Crushed apples were pressed at the pressure of 3 bar (Speidel Hydropresse 20 L; Ofterdingen, Germany) resulting in 30.3 kg of raw juice (RJ) and 15.5 kg of apple pomace 1 (AP1). Raw apple juice was filtrated (Sheet filter 20×20 FZ 20, Zambelli; Vicenza, Italy; Depth filters Seitz K 100, Pall Filterysystems GmbH; Bad Kreuznach, Germany) and pasteurized at 73 °C for ten minutes (Eltac EKA 179; Viersen, Germany) and filled in Bag-in-Box containers (Fig. 2).

Extraction of Pectin and Sugar

Prior to the extraction, the pH value of demineralized water was adjusted to 1 by 37% hydrochloric acid (Carl Roth; Karlsruhe, Germany). The extraction was performed by mixing 22.25 kg of water with 15.5 kg of AP1 (ratio 1.44) and boiled at 90 °C for one hour while constantly being stirred. The mixture was cooled down to 40 °C and then pressed (Vares Hydraulic Profi 18L/2t, Vares Mnichovice a.s.; Mnichovice, Czech Republic). The solid fraction—so called apple pomace 2 (AP2)—was used to produce pellets (P) and the liquid fraction—so called apple pomace extract (APE) was collected. 10.5 kg of APE was mixed with 4.3 kg of 93.8% (w/w) ethanol (Merck; Darmstadt, Germany) and cooled down to 4 °C overnight. The following day, it was pressed by hydraulic press. The gained solid pectin (PT) was dried at 40 °C for seven days (Shel Lab; Oregan, USA) and the ethanolic liquor (EL) was subjected to distillation in order to produce a pectin free apple pomace extract (PFAPE).

Distillation and Production of PFAPE

Batch distillation was performed by a rectification apparatus DN50 (Normag Labor- und Prozesstechnik GmbH;

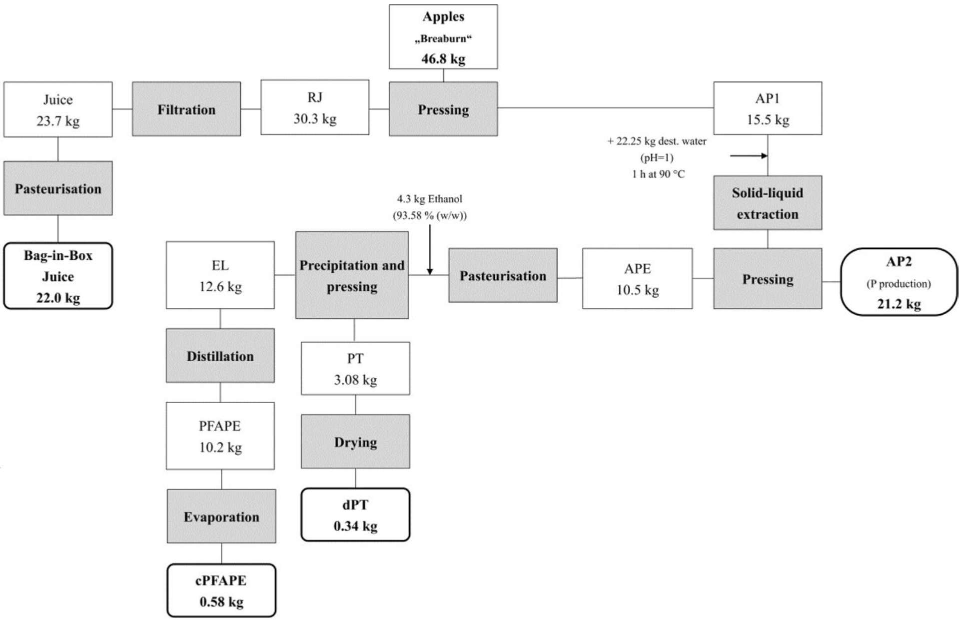


Fig. 2 Production of apple juice, pectin and pectin free apple pomace extract (*AP1* apple pomace 1, *AP2* apple pomace 2, *RJ* raw juice, *P* pellets, *APE* apple pomace extract, *PT* solid pectin, *dPT* dried pectin, *EL* ethanolic liquor, *PFAPE* pectin free apple pomace extract, *cPFAPE* concentrated pectin free apple pomace extract)

Ilmenau, Germany). The column, filled with Raschig-rings, had a diameter of 50 mm and a filling height of 1200 mm, whereby 7 theoretical plates are realized. The capacity of the boiling flask is 10 L and is operated with electric heating device (maximum heat output 1.6 kW). For the separation of EL, a heating power of 0.72 kW was set. At the beginning of the batch distillation, the unit was retracted at reflux ratio 0.2 with a starting head temperature of 76.5 °C. After 165 min, 6.47 kg of apple pomace extract was obtained and 2.37 kg ethanol with purity of 88.34% (w/w) were recovered. PFAPE was concentrated to obtain 0.58 kg concentrated pectin free apple pomace extract (cPFAPE) by evaporation in a scraped surface evaporator (Normag Labor- und Prozesstechnik GmbH; Ilmenau, Germany) for six hours and 30 min at a temperature of 80 °C, pressure of 130 mbar and rotation speed of 150 rpm.

Production and Analysis of Pellets

21.2 kg of AP2 were dried at 60 °C for 24 h (Heraeus Instruments TK 6060; Hanau, Germany) and then used as raw material for pellet production (EcoWorxx Pelletmaker PM22E, EcoWorxx GmbH; Raddestorf, Germany). Moisture content of P was determined at 105 °C until constant weight. Durability was determined according to the standard ISO 17831-1:2015(en) (Solid biofuels—Determination of mechanical durability of pellets and briquettes—Part 1: Pellets") [20] (Pelletsabriebtester Bioenergy Tumbler 1000, Bioenergy Anlagenplanung GmbH; Vienna, Austria). Net calorific value was determined according to ISO 18125:2017(en) (Solid biofuels—Determination of calorific value) [21] (IKA Calorimeter C200, IKA GmbH & Co.; Staufen, Germany).

Determination of Dry Matter

The solid content was determined by using drying oven (Shel Lab; Oregon, USA). Three to five grams of sample was heated for 24 h at the temperature of 105 °C.

Determination of Ash Content

A muffle furnace (Nabertherm S27 Controller L3; Lilienthal Germany) was used for the determination of ash content. The dried samples were heated for two hours at the temperature of 550 °C.

Determination of Sugar Concentrations

The concentrations of sucrose, glucose, and fructose have been determined enzymatic with the commercial kit (EnzytecTM D-Glucose/D-Fructose/Sucrose, R-Biopharm AG; Darmstadt, Germany) as well as by refractometer (0–32%, Greiner Glasinstrumente GmbH; Lemgo, Germany).

Fed-Batch Fermentation of Baker´s Yeast

Large-scale yeast inoculum *Saccharomyces cerevisiae* was kindly provided by Uniferm GmbH & Co; Monheim am Rhein, Germany.

Two fermentations were conducted; one with the molasses and the second one with the mixture of molasses and cPFAPE as carbon source. All the other steps and course of the fermentation were the same for both cultivations. The 15 L bioreactor (Infors, Techfors-S; Bottmingen, Switzerland) was filled with 5 L of sterile tap water and 30 g of monoammonium phosphate (VWR International; Radnor, Pennsylvania, USA). The molasses medium, a sterile mixture of sugar beet and cane molasses, was kindly provided by Uniferm GmbH & Co, Monheim am Rhein, Germany. The medium for the cultivation contained 93% of the molasses and 7% of cPFAPE. Prior to mixing, cPFAPE was first centrifuged (Sorvall RC-5B Plus Superspeed Centrifuge; Thermo Fisher Scientific; Waltham, Massachusetts, USA) and neutralized with a 2.5 M sodium hydroxide solution (Carl Roth; Karlsruhe, Germany). Brix value of 73 was lowered to 44 with the addition of demineralized water. The noticeable solid particles were removed via filtration (Filter paper MN 540 we, ø 150 mm; Düren, Germany) and the medium was sterilised (Eltac EKA 179; Viersen, Germany). 4 kg of substrate (molasses or molasses-cPFAPE mixture) were supplemented with a vitamin stock solution. The bioreactor was inoculated with 180 g of yeast (concentration of 0.737 g/g). The fed-batch cultivation was performed at the temperature range from 30 to 36 °C and the pH-range from 4 to 6.2 (kept at specific value by 25% sulfuric acid (Merck; Darmstadt, Germany)) with molasses/cPFAPE and 10% ammonium solution (Carl Roth; Karlsruhe, Germany) as substrates. The dissolved-oxygen concentration was kept above 10% of air saturation at an impeller speed of 800 rpm at the beginning followed by 1150 rpm. The samples were centrifuged (Minizentrifuge IKA® mini G, IKA Werke GmbH & Co. KG, Staufen im Breisgau, Germany) for 10 min at 6,000 rpm, washed twice with 0.9% NaCl (Merck; Darmstadt, Germany) for the determination of dry yeast biomass and fermentative capacity. The concentration of dry yeast biomass was determined via vacuum furnace (Nabertherm S27 Controller L3; Lilienthal Germany) at 105 °C for 24 h. Fermentative capacity, the increase of the ethanol concentration (Ethanol UV Method, R-Biopharm; Darmstadt, Germany) was determined in two different synthetic doughs (low sugar synthetic dough (LSSD) and high sugar synthetic dough (HSSD)) [22].

Process Simulation

The simulation of continuous distillation was conducted by means of software ChemSep (ChemSep Lite v7.3) (Table 3). Figures were made by softwares e!Sankey 4 and Microsoft Visio 2010.

Table 3 Input parameters for continuous distillation in ChemSep Lite v7.3

Type of simulation	Equilibrium column
Operation	
Configuration	
Operation	Simple distillation
Condenser	Total (liquid product)
Reboiler	Partial (liquid product)
Number of stages	15
Feed stages	12
Properties	
Thermodynamics	
K-value	DECHEMA
Equation of state	Ideal gas law
Activity coefficient	UNIFAC
Vapour pressure	Antoine
Enthalpy	Excess
Enthalpy/exergy	
Reference state	Vapour 298,15 K
Heat of formation	Excluded
Surroundings T	298,15 K
Heat Capacity IG	T correlation
Heat Capacity L	Mol fraction average
Reflux ratio	1.50
Mass fraction water (/)	
Feed	0.727521
Top	0.0930107
Bottom	0.990247

Results and Discussion

Mass and Heat Balance in the Production of Apple Juice, Pectin, Pellets and Pectin Free Apple Pomace Extract

Mass balance of apple processing into apple juice and further into pectin, pellets and pectin free apple pomace extract are presented in Fig. 3. It is important to mention that unlike in industrial production, pectin-degrading enzyme was not used during the production of apple juice in this research.

After shredding and pressing, 30.3 kg of raw apple juice was obtained, meaning 65% of apples was utilized for juice production, which correspond the literature [23]. The losses that remained in the equipment during the production as well as for sampling were taken into consideration. Bag-in-box apple juice contained total sugar concentration of 102.7 g/L, which is in good agreement with the literature [24]. The extraction of AP1 is a critical step from an economic point of view. Namely, the more water added, the more energy is required during the drying process, more ethanol is need for the precipitation and more energy is required for the

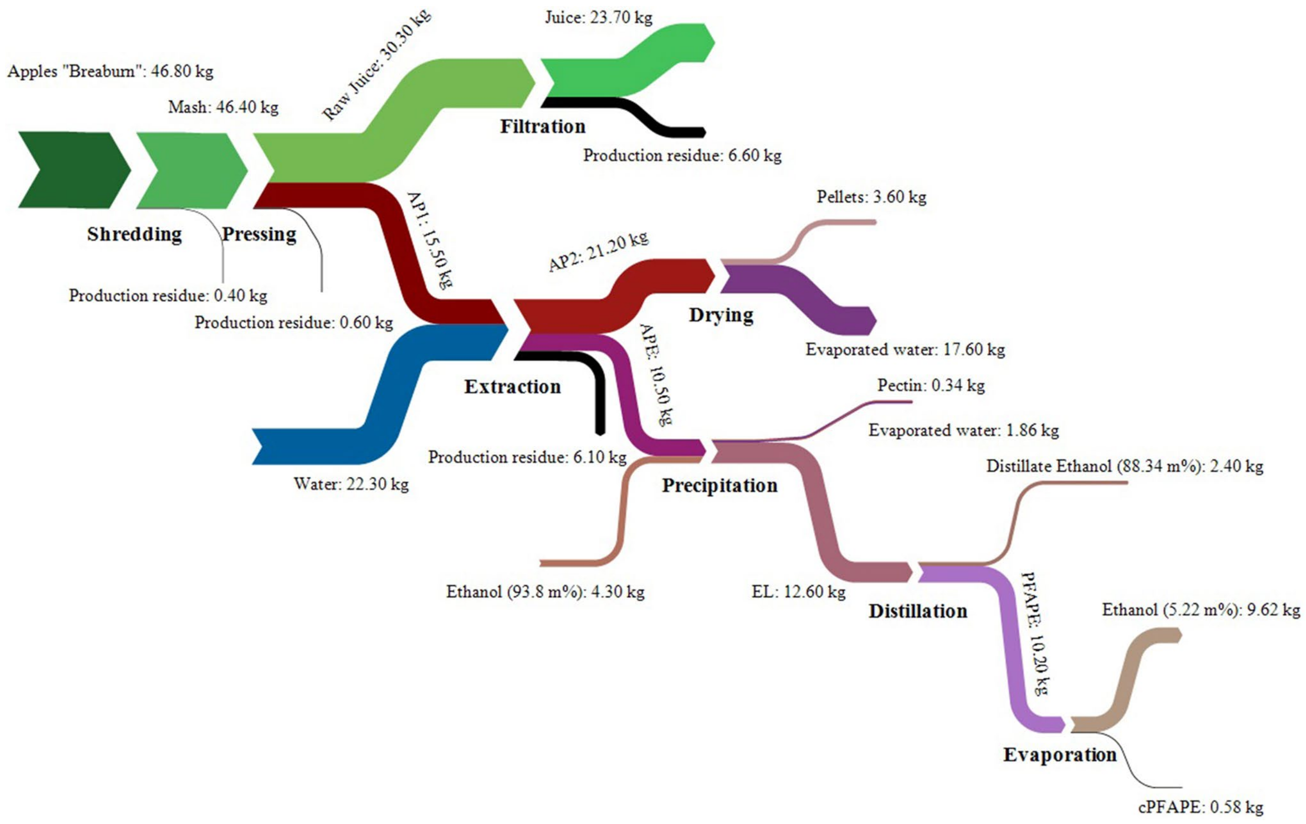


Fig. 3 Mass balance of apple processing into apple juice, pectin, pellets and pectin free apple pomace extract

distillation and concentration processes. In this research, the extraction was conducted with a water/AP1 ratio 1.44 which resulted in 21.2 kg of AP2 and 10.5 kg of APE. Dried AP2 was employed as substrate for pelleting. Apple pellets, with the moisture content of 17.1%, were further analysed. Pellet durability index amounted 96.9%, which is slightly lower than found in literature [16]. However, measured net calorific value of 20.312 MJ/kg is higher than found in literature [25] and very similar to the value obtained with wood pellets [26]. Precipitation of extract with ethanol resulted in 3.08 kg of soluble pectin, i.e. in 0.34 kg of dried pectin. To be exact, AP contained 11.89% of pectin on dry matter (which corresponds to literature in Table 2). Batch distillation proved to be a successful step in recovering ethanol and obtaining PFAPE (Fig. 4). The head temperature was kept at ethanol´s boiling point (78.3 °C). Starting bottom temperature was 82 °C and by having less and less ethanol in the fraction and more water content, the temperature tended to rise. The reflux ratio could be kept below 1 for 108 min. Then it required to be higher and was kept at 7 for 37 min. The distillation was stopped as the head temperature suddenly increased because of the presence of water in the distillate. By distillation 2.4 kg of 88.34% (w/w) ethanol was recovered and 10.2 kg PFAPE obtained as bottom product.

APE still contained ethanol (5.22% (w/w)) and water which were removed by evaporation. Obtained final product cPFAPE amounted 0.58 kg with Brix value of 73.

Energy demands for drying of AP2, drying of pectin, distillation and evaporation were calculated (Fig. 5). As mentioned the extraction is a critical step. Water was mixed with AP1 in ratio 1.44. It resulted in 21.2 kg of AP2, which required energy of 2.892 $\mathrm{MJ/kg_{AP1}}$ for the drying process to evaporate 17.6 kg of water, considering an evaporation enthalpy of 2546.5 kJ/kg [27]. This step consumes the most energy. To gain dPT the energy demand was 0.306 $\mathrm{MJ/kg_{AP1}}$. Batch distillation process consumed 1.833 $\mathrm{MJ/kg_{AP1}}$, based on the evaporation enthalpy of ethanol 839 kJ/kg [27]. 1.621 $\mathrm{MJ/kg_{AP1}}$ was required in the evaporation process to gain cPFAPE. Calculated total energy obtained from the pellets combustion is as high as 3.938 $\mathrm{MJ/kg_{AP1}}$. However, the usual energy efficiency of boilers is approximately 90% [28], meaning the pellets are generating 3.544 $\mathrm{MJ/kg_{AP1}}$ energy. Combusting the pellets does not cover all energy demands required for the drying of AP2, distillation, evaporation and drying of pectin; an additional input of 3.108 $\mathrm{MJ/kg_{AP1}}$ is required. It might be more useful to use the pellets for more lucrative purposes such as feed (about 300 $/ton) or anaerobic digestion.

Fig. 4 Relation of temperatures and reflux ratio during the batch distillation

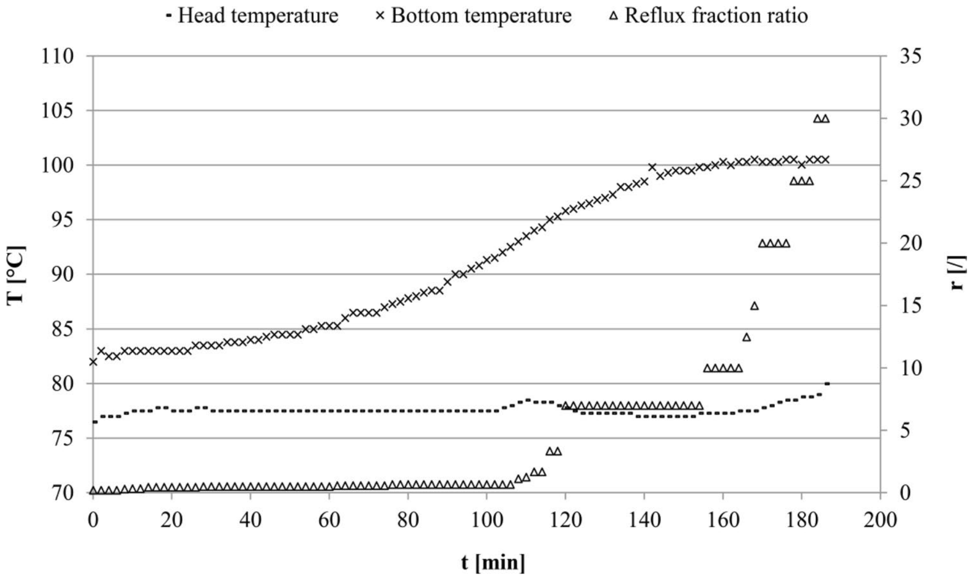


Fig. 5 Heat balance in the production of pectin, pellets and pectin free apple pomace extract in MJ/kg$_{AP1}$

Fed-Batch Cultivation

cPFAPE was tested in fed-batch fermentation of baker´s yeast in order to explore its potential as an alternative to overpriced molasses [29]. The results are presented in Table 4. Concentration of dry yeast biomass obtained on the medium consisted of molasses and cPFAPE is slightly lower than the yield obtained on the medium containing only molasses. However, baker´s yeast end concentration is still higher than found in literature [23]. It has been reported, and was also proved in this research, that baker´s yeast shows lower fermentative capacity in HSSD-medium, due to the overexpression of invertase and intrinsic osmotolerance triggered by high sugar environment [22]. Slightly lower production of ethanol in HSSD is achieved by the yeast grown on the medium containing cPFAPE. However, the higher fermentative capacity is achieved in LSSD medium by the yeast produced on cPFAPE. These results indicate that cPFAPE

Table 4 Maximum biomass yield (on dry matter in g) and fermentative capacity in two synthetic doughs (in mmol$_{Ethanol}$/g/h) of *Saccharomyces cerevisiae* produced on molasses and molasses and cPFAPE

Medium	Dry yeast biomass (g)	Fermentative capacity (mmol$_{Ethanol}$/g/h)	
		HSSD	LSSD
Molasses	630	1.806	4.014
Molasses and cPFAPE	620	1.764	4.181

can be used as an alternative substrate for the production of baker´s yeast. cPFAPE ´s Brix value was 73, which is significantly higher than the value in diluted molasses used in baker´s yeast production but nearly the same as the Brix value of pure molasses [30]. Considering the high prices of molasses, if only a portion of molasses is replaced with cPFAPE (for example 10%), it would significantly reduce the costs of producing baker´s yeast. If baker´s yeast manufacture requires 100.000 tonnes of molasses/year, with the substitution of 10%, the cost reduction would amount $ 1 million. Additionally cPFAPE is being converted from the waste by-product into valuable source of nutrients which contributes to integrated sustainability in the industrial environment, where the waste from one industrial process is used as feedstock for another [31].

Industrial Concept of Biorefinery

In this study, apple juice was successfully produced at pilot scale. Also by-product apple pomace was processed so that three valuable products were obtained. However, to process large amounts of apple pomace, modifications have to be implemented. As previously mentioned, the most critical step in this work flow is the extraction process, considering that water needs to be removed in latter phases which require large amounts of energy. Batch distillation is not profitable on industrial scale. That is why the simulation of continuous distillation was performed and four scenarios were developed (Table 5). Different water/AP1 ratios for extraction process were investigated (1.08 and 0.72) as well as the same one used in the experimental part of batch distillation (1.44), in order to reduce the energy input into the overall process. We assumed that the water content in AP2 was constant for water/AP1 ratios > 0.4.

The energy demand is reduced for every step, except for AP2 and pectin drying and combustion of pellets, which remained the same. When applying water/AP1 ratio of 1.44 in extraction process, the energy demand input for overall process, in which continuous distillation is applied, is almost 60% reduced than in process in which batch distillation is used (reduction of 1.598 MJ/kg$_{AP1}$). Simulation showed that if 7.068 kg of water is mixed with 15.5 kg of AP1 (ratio 0.455) in the extraction process, the energy demand for overall process would be entirely covered by the combustion of pellets (Fig. 6).

The developed biorefinery concept is shown in Fig. 7. Besides the equipment for the industrial production of apple juice, the distillation apparatus and equipment for producing pectin are integrated in the plant. By producing and combusting pellets, the energy demand can be covered in this chain, with the emphasis of carefully designing the extraction process. cPFAPE partly substitutes raw material molasses in the production of baker´s yeast. This concept does not only include the valorisation of the entire waste steam but also generates energy.

Considering the results obtained in this study and amount of apple juice produced in Germany in 2017 (Table 1), the corresponding amount of apple pomace produced is approx. 398,000 tonnes, i.e. 73,400 tonnes on dry matter. The amount of pectin that could be recovered equals 8,730 tonnes, which corresponds to almost 15% of global production accomplished in year 2015 and has worth of more than $ 130 million. Amount of pellets that could be produced equals 92,400 tonnes, which by combusting generate energy of over 1.4 million GJ. The amount of concentrated pectin free pomace extract produced would be over 15,000 tonnes.

Table 5 Theoretical scenarios of energy requirements and demand by applying different water/AP1 ratio for extraction process

Ratio water/AP1 for extraction process	1.44	1.08	0.72
Energy requirements (MJ/kg$_{AP1}$)			
Drying of apple pomace 2	2.892	2.892	2.892
Continuous distillation	0.718	0.538	0.359
Evaporation	1.621	1.216	0.811
Drying of pectin	0.306	0.306	0.306
Total	5.536	4.951	4.366
Energy generated from pellets	3.938	3.938	3.938
Energy demand	1.598	1.013	0.428

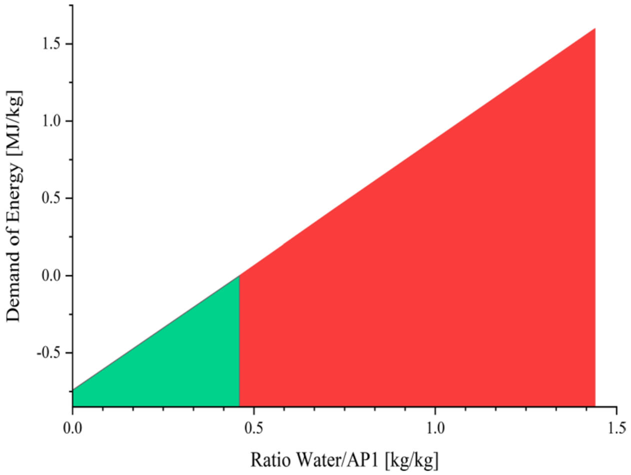


Fig. 6 Energy input (in MJ/kg$_{AP1}$) required for the process in correlation with ratio water/AP1

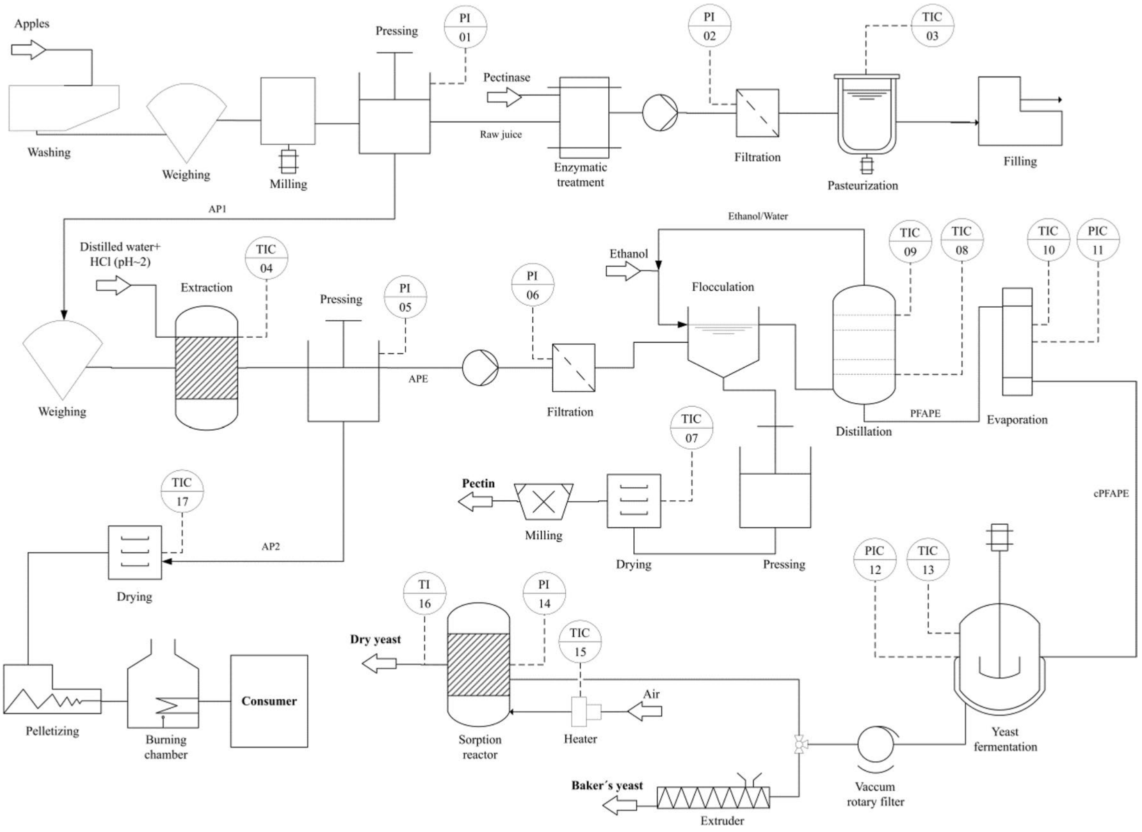


Fig. 7 Apple juice production turned into biorefinery platform

Conclusions

This study demonstrated how by-product of apple juice production can be fully valorised, resulting in pectin, pellets and pectin free apple pomace extract. The process of apple juice production was similar to the industrial process, only commercial enzyme of any kind and ascorbic acid have not been used. The critical step of extraction has been discussed as well as the possible scenarios of industrial continuous distillation, considering batch process was applied in recovering ethanol. 3.6 kg of pellets were produced in this work and the net calorific value of 20.3 MJ/kg is practically the same as the one reported for wood pellets. Apple pomace proved to contain 11.9% of pectin. Concentrated pectin free apple pomace extract showed potential to be employed as a carbon source for the growth of baker´s yeast. Slightly lower biomass yield is obtained in the medium containing cPFAPE and molasses than in the medium containing only molasses. However, yeast produced on alternative substrate possessed a bit higher fermentative activity than the one produced on molasses. By reshaping this production, a biorefinery platform in which waste from one production stream is used as feedstock in another industrial process, could be set up. It would provide not only value-added products but would also generate energy for its own use. Scaling up calculations showed that almost 15% of global pectin production could be covered by this biorefinery, 15,000 tonnes of alternative raw medium for baker´s yeast production could be produced and 92,420.8 tonnes of pellets would generate approx. 20.2 GJ per tonne of pellets. One of the problems for setting up a biorefinery concept is the raw material availability. However, apple pomace is widely available and eligible for multiple purposes. Further investigations regarding extraction and distillation process are necessary in order to turn this production into zero discharge biorefinery process.

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Compliance with Ethical Standards

Conflict of interest The authors declare that they have no conflict of interest.

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