

Original Research Article

Biogas Production Potential from Anaerobic Co-digestion of Grape Pomace

ABSTRACT

Grape cultivation and wine production has been practiced since 7000 BC in ancient China. Today, top wine producing countries are France, Italy, and Spain, with the United States. New York State is the third largest wine producing state in the US, with over 28 million gallons produced in 2017. Wine pomace, the residue from wine making after pressing could be used for the production of electricity and heat replacing fossil resources. One alternative route could be anaerobic fermentation of wine making residues for the production of electricity, heat from the produced biogas.

This research investigated the cumulative biogas production from anaerobic fermentation of differently prepared red wine grape pomace. Red wine grape pomace was used as received, prepared by blending using a laboratory benchtop blender, refined using a Valley beater apparatus, and cooking the refined red wine grape pomace for 2 hours at 98°C. The pH of each solution was adjusted to 8.50 with a 20% Calcium Hydroxide (Ca(OH)₂) solution. 300 g of each solution and 30 ml of bacteria inoculate was filled into a 500 ml Erlenmeyer flask that contained a magnetic stirrer. The anaerobic fermentation experiment have been run in duplicate, lasted for up to 170 hours, at a temperature of 39°C ± 2°C.

Untreated red wine grape pomace had the lowest cumulative biogas production of 93 ml and 151 ml.

Blended grapes showed a cumulative biogas production of 283 ml and 243 ml respectively. Refined red wine grape pomace generated the highest biogas production with 566 ml and 864 ml, followed by refined and cooked red wine grape pomace with a biogas production of 365 ml and 830 ml. The maximum biogas composition without CO₂ was 70% and the minimum biogas composition was 55%.

Pre-treatment such as refining, blending, and heat treatment can increase biogas production and lead to a possible lower retention time in the fermentation vessel due faster biomass conversion.

Keywords: Anaerobic digestion, biogas, co-digestion, energy production, fermentation, grapes

1. INTRODUCTION

Grape cultivation and wine production has been practiced for thousands of years. The earliest evidence of winemaking has been dated to 7000 BC in China, and in 6000 BC in the Caucasus Mountains, Zagros Mountains, Euphrates River Valley, and Southeastern Anatolia. Winemaking spread to Europe through the Greek and Phoenician expansion period between 1200 and 800 BC, where wine was beginning to be traded commercially (A Curious

and Captivating History of Wine, n.d.). Grape growing had spread throughout Europe by around 100 BC as a result of the Roman expansion, and took its roots in the land and the culture alike [1].

In ancient Egypt, the role of wine was clearly documented with hieroglyphics on storage vessels, most of which were preserved in pyramids, the tombs of pharaohs. In the earliest civilizations, wine was a sign of opulence [2]. Wine was at least ten times more expensive than beer, especially when considering the cost of transportation [3]. The cost of transportation was also a burden in ancient Egypt since wild grapes were not able to grow naturally in this region. However, Egyptians eventually transplanted grape vines into the Nile Delta to meet demands [2].

As the Roman Empire started its journey of conquests, many of the Romans' cultural, linguistic, and agricultural developments were appropriated from the Greeks. So, the Romans quickly began to adopt winemaking and drinking into their culture. As such a fast-growing empire, the Romans were able to conjure all the resources needed for booming wine production. According to *A History of the World in Six Glasses*, "By 70 CE, the Roman writer Pliny the Elder estimated that there were eighty wines of note in the Roman world, two-thirds of which were grown in Italy". It could be said that winemaking started in Greece but was perfected in Rome [3]. The previous method of wine storage in clay vessels called amphorae, was replaced by the Romans. They began to store wine in wooden barrels, which would slightly lengthen the life of the wine. Even with the advancements, it is assumed that all wine created during this period was consumed within a year of vintage. Since the wine making conditions were not sterile, it would spoil easily. Spoiled wine was dealt with by adding flavorings like honey, or saltwater [4]. And as the Roman empire conquered more lands, their customs were adopted all over the world. This rudimentary wine making process, popularized by the Romans, would evolve into the process we know today.

Today, the top wine producing countries are France, Italy, and Spain, with the United States and Australia becoming more serious producers within about the last 50 years. New York State is the third largest wine producing state in the US, with over 28 million gallons produced in 2017. The industry has a \$6.65 billion annual economic impact and produces around 57,000 tons of grapes every year (*How Big Is New York's Wine Business?*, 2020) [5]. The two major grapes grown for winemaking are red and white, there are many different varieties of each, but this is the major distinction that must be noted. White wine grapes, such as those used to make Pinot Noir and Chardonnay, are naturally thinner skinned, and are therefore more susceptible to environmental conditions. Whereas red grapes varieties, such as those used to make Cabernet Sauvignon and Merlot, are thicker skinned and much more resilient. Another important group of chemicals that are crucial in the success of a wine are phenolics, specifically tannins. Tannins contribute greatly to the feel of a wine in the mouth, or the dryness of the wine. A good balance of tannins and other flavor molecules is a necessary part of the winemaking process.

After the grapes are grown and fully ripened, they are harvested and transported to the winery. The process changes here depending on the grapes, either white or red. Red grapes hold most of their tannins and flavor compounds in their thick skin. To absorb those compounds into the wine, these varieties are fermented with the skins and stems intact. Because white grape varieties are typically thinner skinned, most of the tannins are present in the grape juice already. In order to keep the wine from being too harsh, these grapes are pressed before they are fermented using a pneumatic press. The press is made up of a tank where the grapes are loaded, then an elastic balloon is inflated within the tank, squeezing the juice out of the grapes through a screen at the bottom of the tank, separating it from the skins, followed by fermenting the juice [6].

The fermentation process is what essentially turns the grape juice into wine. Grapes already contain yeast in their biological makeup, this is known as "wild yeast" [7]. Some wineries, particularly organic ones, only use wild yeasts. Commercial yeasts are more common in the

industry because of their reliability and their application can be organized in a consistent way. The most common variety is *Saccharomyces cerevisiae*, the same yeast used in the beer brewing process. If fermentation were to stall when using wild yeasts, commercial yeasts can be added to kick start the process [7].

Depending on the wine being produced, fermentation is carried out at different temperatures. Red wines are typically fermented at higher temperatures (80-90 degrees F) in order to extract the compounds from the skins and stems. In the case of white wines fermentation is carried out at lower temperatures (around 50 degrees F) so that the fruity flavors compounds are preserved and not destroyed by the heat [6]. Fermentation success is greatly impacted by the contact between the skins and the juice. Yeast produces both alcohol and carbon dioxide from sugar, the carbon dioxide rises to the top of the tank and, in the case of red wines, is trapped by the skins, raising them up and preventing contact with the juice. An important part of the fermentation process is called cap management. The cap is the skins and stems that rise to the top of the tank due to the carbon dioxide. Many different techniques of cap management are used, but the basic principle involves pushing the cap down into the juice and releasing the carbon dioxide. This can be accomplished by a physical pushing down of the cap, known as punching, or by recycling the juice from the bottom of the tank through a hose, and pushing down the cap with the pressurized juice stream, this is known as pumping [8]. The technique selected can change the flavors present in the wine, since pumping is gentler on the grapes, it typically results in a less bitter wine than punching does.

After fermentation is completed, the juice present in the tank, referred to as grape must, is drained out and moves on to the next step in the process, this is known as free run wine and is

Typically, where the best tasting and most desirable bottles are taken from a particular batch. The remaining skins and stems, known as grape marc, are then sent to a barrel press. This is a very traditional machine and has been used in winemaking for centuries. It is a completely mechanical process in which the grape marc is scooped into a cask, and a metal press is slowly cranked to squeeze out additional must from the marc, this is known as press wine. The remaining marc, or pomace, is then typically discarded or can be used as a fertilizer with further processing, but it can also be applied elsewhere [9].

Wine waste, also referred to as pomace, is the pressate of skins and stems that is leftover after grape juicing. Depending on the type of grape being pressed, and ultimately the type of wine being produced, wineries will press at different stages in the grape processing. White grapes are naturally sweeter, and have higher levels of phenolics, such as tannin, already present in the grape juice [10].

In order to prevent the wine from being too harsh or strong, the grapes are pressed almost immediately, and only the juice is fermented. Red grapes are thicker skinned, and this have most of their phenolics present in the skins and stems. To create a richer tasting wine, the grapes are often fermented before pressing and, depending on the wine, even fermented with their stems still attached. This allows the grape juice to absorb some of those compounds, and results in a more complex wine [6].

As a result of these differences, no two wineries will produce the same waste. Therefore, finding ways to utilize the waste is difficult because there will always be differences in the amount of organic compounds present in the skins and stems of the grapes depending on what kind of grapes they are, what region they are from, how they were processed, and how long they have been stored for.

Due to the diverse composition of wine waste, research has taken its application in many directions. Recent research has begun on using wine pomace in an anaerobic digestion process to produce biogas, as well as further processing the waste to produce biodiesel. A recent study at the University of Auckland in New Zealand concluded that a completely biodegradable plastic can be produced from wine pomace. It is done in a four-step process

where the tannins are extracted from the pomace through centrifugation, and the collected and concentrated to form a biofilm [11].

Because of the natural antioxidant properties of tannin, their research has led them to pursue development of the biofilm into an “active packaging” that could kill bacteria on food and medical products. Research has also been conducted into using grape pomace to produce bioethanol. A study conducted under the Journal of Agricultural and Food Chemistry concluded that with fresh grape pomace (unfermented, white) they were able to obtain an ethanol concentration of about 0.4 g/g DM (a 78% yield) and with fermented grape pomace (from red wine production) were able to obtain ethanol concentrations of around 0.1 g/g dry content. Further research into ethanol recovery as well as effective pretreatment could raise these numbers significantly [12].

Another way in handling waste from wine making is Anaerobic Digestion (AD), which is a sequence of biological processes used to degrade organic material and produce mainly biogas under anaerobic conditions [13]. Feedstock for AD can be farm-based including agricultural residues, crops, plant biomass, as well as sewage sludge from wastewater treatment operations or industry based organic waste residues. Each feedstock requires different reactors to achieve best operation results. For research application mostly batch reactors are used [14].

The following manuscript describes the laboratory scale batch fermentation research using wine grapes pomace after pressing as feedstock. The research for determination of the biogas production potential is based on procedures established by Dölle and Hughes for co-digesting Hyacinth (*Eichhornia crassipes*) and Cow Manure [15].

The research was conducted at the Chemical Engineering Departments at the State University of New York (SUNY), College of Environmental Science and forestry (ESF).

2. MATERIAL AND METHODS

2.1. Materials

2.1.1. Red Wine Grape Pomace

Red Wine Grape Pomace (RWGP) with a solids content of 40.88% was collected in a 5-gallon pail from a nearby winery in the Finger Lakes region located on the west shore of Seneca Lake in New York State. The 5-gallon pail was kept in a cold room at 41°F (5°C) prior to the start of the fermentation experiment.

2.1.2. Fermentation Inoculate

Fermentation Inoculate (FI) was obtained from a nearby anaerobic sludge blanket reactor in the Syracuse, New York area. The FI had a solids content of 3.44% and was kept in a cold room at 41°F (5°C) prior to the start of the fermentation experiment.

2.1.3. Barrier Fluid

Preparation of the barrier fluid, which does not allow the adsorption of CO₂ into the liquid, was based on DIN 38414 [16]. First, 1000 ml of deionized water was heated under stirring in a 1500 ml glass beaker using Thermo Scientific brant stirring hotplate and a magnetic stir bar. After a temperature of 40°C was reached, 30 ml of sulfuric acid (H₂SO₄; ρ=1,84 g/ml). Then 200 g of sodium sulfate dehydrate (Na₂SO₄) is added slowly to the diluted sulfuric acid solution. The solution is stirred until all sodium sulfate dehydrate is dissolved in the solution. Second, in a 150 ml glass beaker methyl orange powder is dissolved in 100 ml of distilled water under constant stirring at a temperature of 20°C.

Third, a few drops of the Methyl orange solution are added to the barrier fluid to allow for easier visualization. The color can be adjusted to either a lighter or a darker orange by adding more or less drops to the barrier solution.

Forth, the barrier solution should be stored at room temperature to prohibit crystallization. If crystallization occurs, the crystallization can be reversed easily by heating and stirring the barrier solution to of 40°C.

2.1.4. Absorbent Fluid

The Absorbent fluid was prepared using a 1000 ml glass beaker filled with 500 ml of deionized water with 20°C. The beaker was placed on a Thermo Scientific brand stirring hotplate, and under stirring using a magnetic stirrer. Sodium Hydroxide (NaOH) pellets were added until a final NaOH solution of 10% was achieved. The prepared adsorbent solution was filled in a clear PVC container and covered until used.

2.2. Laboratory Benchtop Anaerobic Fermentation System

Figure 1. shows the used Laboratory Benchtop Anaerobic Fermentation (LBAF) system for this research, as described by Dölle and Hughes [15]. The LBAF system consisted of a Fisher Scientific brand 7.25 x 7.25 digital heating-stirring hot plate (1). A 2.0 l glass beaker (2) filled with deionized water (12), heated by the stirring hot plate. The glass beaker serves as the heating vessel that provides the desired anaerobic fermentation temperature of approximately 39 °C. A 500 ml Erlenmeyer flask with a 40 mm magnetic stirrer serves as the Anaerobic Fermentation Vessel (AFV) (3). A rubber stopper (4) seals the reactor vessel. The rubber stopper contains a glued in 1/4" Outside Diameter (OD) x 1/8" Inside Diameter (ID) Male National Pipe Thread (MNPT) Nylon male adaptor fitting that is connected to a Polyvinyl Chloride (PVC) hose with 1/4" OD and 1/8" ID (5). The PVC hose contains a shut-off clamps (6) that allow to seal off the AFV if closed. If opened the produced biogas (13) from the biomass suspension (11) can flow through PVC Tee (7) into a inverted installed 120 ml PVC graduated cylinder (9) if shut-off valve (8) is closed. The graduated cylinder (9) serves as the displacement vessel (9) for the barrier fluid (14). The graduated cylinder has a 1/4" OD x 1/8" ID MNPT Nylon male adaptor glued in on the bottom connected to a PVC hose having 1/4" OD and 1/8" ID (5). Displacement vessel (9) is located approximately 5 mm above the bottom of a 500 ml clear PVC beaker, which serves as the barrier fluid reservoir (10). If shut-off valve 6 left of the tee (7) is closed and shut-off valve (8) in the PVC hose (5) line right of the tee (7) is opened, the barrier fluid can be moved back into the displacement vessel (9) using the attached 3-way rubber suction ball (15). If a 50 ml PVC syringe replaces the suction ball (15), biogas can be extracted from the displacement vessel for analyses.

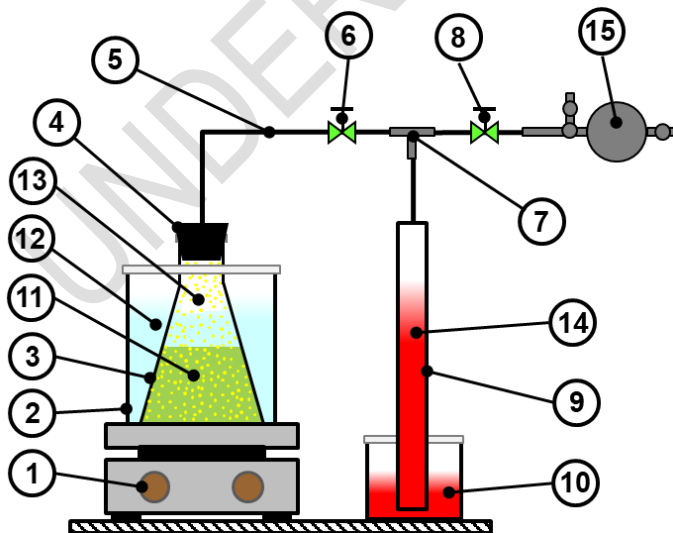


Fig. 1. Laboratory Benchtop Anaerobic Fermentation system: 1) Digital heating-stirring hot plate, 2) Heating vessel, 3) Fermentation vessel, 4) Rubber stopper, 5) PVC hose, 6) Shut-off valve, 7) Tee, 8) Shut-off valve, 9) Barrier fluid displacement vessel, 10) Barrier fluid reservoir, 11) Biomass suspension, 12) Heated water, 13) Biogas, 14) Barrier fluid, 15) 3-way rubber suction ball [15]

2.2.1 Operation of the LBAF

To operate the LBAF, approximately 350 g prepared biomass solution was filled into a pre-weighted digester vessel (3) with the magnetic stirrer. Next, the digester vessel was weighed to obtain the wet sample weight measurements. Then the digester vessel (3) was sealed with rubber stopper (4) and its attachments show in Figure 2. Several layers of Parafilm were used to maintain a tight seal. The digester vessel was incubated in heating vessel (2) that is placed on a digital heating stirring hot plate (1), containing 1200 ml distilled water at 39°C for the duration of the experimental trials. Valve (6) was closed at the start of the experiment. The rotation of the magnetic stirrer was adjusted that the biomass solution (11) turns slowly in the digester vessel (2). Additional distilled water was added to the beaker until the water level reached the neck of the Erlenmeyer flask digestion vessel (3). The water served as a water jacket to control the temperature of the mixture in the digestion vessel (3). The temperature and volume of the water bath and the stirring speed were adjusted during the trial to be as close as possible to the initial set value.

Next, the barrier fluid (14) was sucked into the barrier fluid displacement vessel (9) using the 3-way rubber suction ball (15), till it reached the top of the barrier fluid displacement vessel (9). Then, clamp valve (8) was closed, and clamp valve (6) was opened. As the produced biogas (13) was drawn from the headspace of the reactor into the barrier fluid displacement vessel (9) replacing the barrier fluid (14). Biogas generation was allowed to proceed, and biogas generation measurements were taken until biogas generation was deemed minimal or nonexistent. This time and length of each AD test varied between tests but was approximately five to eight days.

After each biogas measurement barrier fluid (14) was succeed back into the displacement vessel (9) until it reached the top, using the 3-way ball suction ball (15) by opening clamp valve (6) and opening clam vale (8). Thereafter clamp valve (8) is closed and clam valve (6) is opened, allowing biogas flow to the displacement vessel (9).

2.3. Laboratory Benchtop Methane Analyzer System

A Laboratory Benchtop Methane Analyzer (LBMA) system was designed, build, and installed according to Figure 2. The LBMA system consisted of a 500 ml clear PVC Container which serves as the solvent fluid reservoir (1). An inverted installed 120 ml PVC graduated cylinder serves as the displacement vessel (2) for the adsorbent fluid (10). The displacement vessel (2) is located approximately 5 mm above the bottom of a 500 ml clear PVC beaker which serves as the solvent fluid reservoir (1). The graduated cylinder has a 1/4" OD x 1/8" ID MNPT Nylon male adaptor glued in on the bottom. A PVC hose having 1/4" OD and 1/8" ID (3) is connected to either side of a Tee (4). The Tee (4) has on the left and right PVC hose line a shut-off clamp (5) and (6) installed. On the right side a 3-way rubber suction ball (7) is attached to the PVC hose. On the left side a 50 ml syringe (8) can be attached, containing the biogas (9) for analyzation.

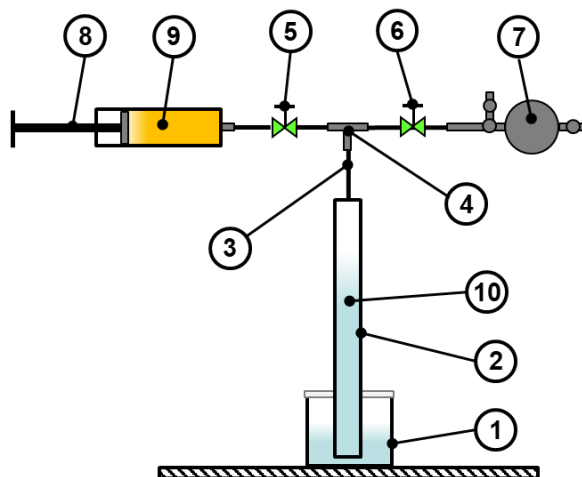


Fig. 2. Laboratory Benchtop Methane Analyses System: 1) Solvent reservoir 2) Solvent displacement vessel 3) PVC hose, 4) Tee, 5) Shut-off valve, 6) Shut-off valve, 7) 3-way rubber suction ball, 8) 50 ml syringe, 9) Biogas, 10) Solvent [15]

2.3.1 Operation of the LBMA

If the left shut-off valve (5) is closed and the right shut-off valve (6) is open the solvent fluid can be moved into the displacement vessel (9) using the attached 3-way rubber suction ball (7) to the desired height. Then shut-off (6) is closed. Syringe (8) containing biogas (9) is attached and shut-off valve (5) is opened. Biogas (9) contained in syringe (8) is pressed into the displacement vessel (2) replacing the adsorbent fluid (10). The adsorbent fluid will then adsorb CO₂ contained in the biogas and move back into the displacement vessel. The difference between the biogas volume pressed into the displacement vessel and the volume of the adsorbent fluid moved back into the displacement vessel is the true biogas content without CO₂.

2.4. Testing Procedures

The following section describes the procedures used for this research project. Each sample weight was determined using a Denver Instrument SI-234 analytical balance.

The Solids Content (SC) of the samples was determined based on modified TAPPI test method T412 om-06 "Moisture in pulp, paper and paperboard" [17] using a 70.7 l (2.5 cuft) Thelco drying oven set to 105°C.

Temperature and pH measurements were conducted using a portable Accumet AP85 pH/temperature/Conductivity meter.

Refining of the grapes was done in accordance to TAPPI test method T 200 sp-06 "Laboratory beating of pulp (Valley beater method)" [18].

Blending of the red wine grapes was done using a 1.5 l benchtop laboratory blender/mixer.

Temperature and pH measurements were conducted using a portable Accumet AP85 pH/temperature/Conductivity meter.

Solids Content (SC) of a given test sample was measured using marked 50 ml aluminum sample trays, in which approximately 30 to 45 ml of the test sample was added. Next, these samples were weighed to obtain their wet sample weight, and then placed in a ~105°C oven to dry for 24 hours. After drying the samples were weighed again to determine their dry weight measurements.

3. RESEARCH EXECUTION, RESULTS, AND DISCUSSION

3.1. Material preparation:

Preserved RWGP feedstock materials from the 41°F (5°C) cold room was prepared as follow:

Refining of the grapes followed TAPPI test method T 200 sp-06. However, the consistency of refining was increased to 7.01% because the red wine grape feedstock allowed operation of the valley Beater at a higher consistency. The final consistency of refining was 7.01%.

Blending of the red wine grapes in 1.5 l benchtop laboratory blender/mixer was done by adding a volume of 600 ml of red wine grapes to the blender, followed by adding tap water to the 1000ml mark. Blending was done for 60 seconds. The final consistency of the blended red wine grape solution was 7.98%.

Boiling of the blended grapes was done for 2 hours at 98°C. the final solids content of the boiled red wine grape suspension was 9.34%.

3.2. Experimental procedure of the anaerobic fermentation experiment

A total of four AD experiments were conducted in duplicate with the RWGP as follows: (i) blended grapes, (ii) unprepared grapes, (iii) refined grapes, and (iv) refined and boiled grapes using the LBAF system. Before the prepared biomass mixtures were prepared, the best solids content for stirring using a magnetic stirrer was evaluated prior to the experiments. Then the mixtures were diluted with tap water to a target solids content for the grapes and blended grapes of 2.5%, for the boiled grapes a solids content of 7.0%, and for the refined grapes a 3% solids content. The pH was adjusted to 8.50 with a 20% Calcium Hydroxide ($\text{Ca}(\text{OH})_2$) solution.

From each solution, the anaerobic digestion solution was prepared by filling approximately 300 g of the solution into a 500 ml Erlenmeyer flask that contained a 40 mm magnetic stirrer. To each flask 30 ml of inoculate bacteria with a solids content of 3.44% were added.

AD tests were performed at a temperature of $39^\circ\text{C} \pm 2^\circ\text{C}$ for the duration of the experimental trials

3.1. Results and Discussion

Figure 3 shows the cumulative biogas production of the different prepared RWGP feed stock referred to as: (i) blended grapes, (ii) unprepared grapes, (iii) refined grapes, and (iv) refined and boiled grapes

Anaerobic fermentation experiment 1 and 2 of the blended grapes used RWGP prepared in a laboratory blender and revealed a Cumulative Biogas Production (CBG) of 283 ml and 243 ml respectively.

Experiment 1 and 2 for the RWGP prepared by refining utilizing TAPPI test method T 200 sp-06 followed by boiling the suspension for 2 hours at 98°C showed a CBG of 365 ml and 830 ml respectively.

The experiment that used refined red wine grape pomace prepared to TAPPI test method T 200 sp-06, gave a CBG of 566 ml and 864 ml for experiment 1 and 2 respectively.

Experiment 1 and 2 for the grapes only anaerobic fermentation experiment revealed a CBG of 93 ml and 151 ml respectively.

The maximum biogas composition without CO_2 was 70% and the minimum biogas composition was 55%.

Anaerobic fermentation of unmodified grapes was conducted for 120 hours. After 120 hours, no biogas production could be observed and the experiment was stopped. A pH of 6.2 was measured after the experiment was stopped.

The fermentation experiment for blended grapes, refined grapes, and refined and boiled grapes lasted for 170 hours. After 170 hours no biogas production could be observed and the experiment was stopped. The pH of the final anaerobic fermentation solution was 6.3 for the blended grapes, 5.9 for the refined grapes and 6.4 for the boiled grapes.

The highest CBG as shown in Figure 3., could be observed from the refined grapes with a range between 566 ml and 864 ml, followed by refined and boiled grapes with a range between 365 ml and 830 ml, and blended grapes with a range of 242 ml to 283 ml.

Fermenting Grapes without pre-preparation, showed the lowest CBG production range of 93 ml to 151 ml.

It can be concluded, that a fibrillating pre-preparation as refining and or blending can increase the biogas production. Additional heat treatment may increase biogas production as well. All treatments, most likely can reduce retention time in the fermentation vessels due to the higher biogas production per time increment and the consumption and conversion of the feedstock biomass into biogas.

Further research should focus on biomass reduction of the feedstock and biogas composition of the produced biogas.

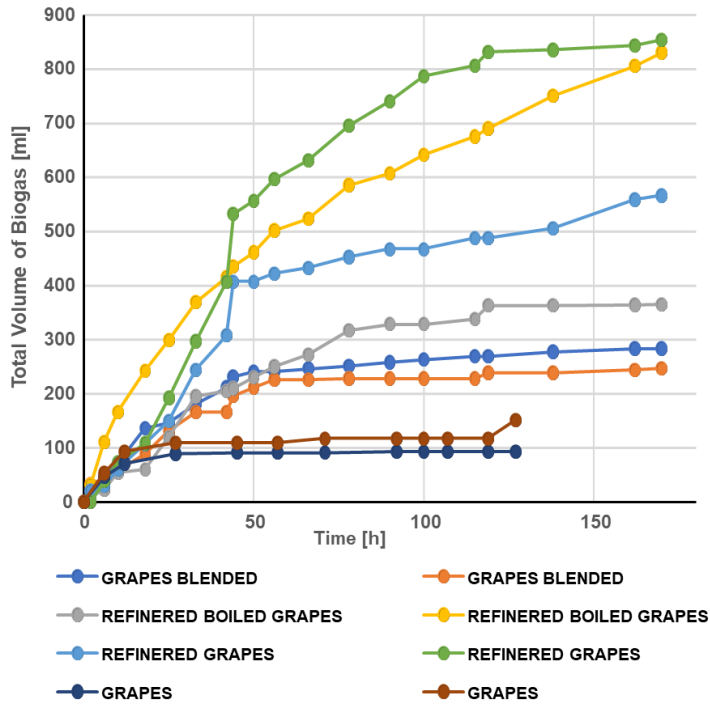


Fig. 3. Cumulative biogas production over time for different prepared grapes feedstock

CONCLUSION

The cumulative biogas production by anaerobic fermentation of different prepared red wine grape pomace was. The collected red wine grape pomace preparation was used as received, prepared by blending using a laboratory benchtop blender, refined using a Valley beater apparatus, and cooking the refined red wine grape pomace for 2 hours at 98°C. The pH of each solution was adjusted to 8.50 with a 20% Calcium Hydroxide ($\text{Ca}(\text{OH})_2$) solution. 300 g of each solution and 30 ml of bacteria inoculate was filled into a 500 ml Erlenmeyer flask that contained a magnetic stirrer. The anaerobic fermentation experiment have been run in duplicate, lasted for up to 170 hours, at a temperature of $39^\circ\text{C} \pm 2^\circ\text{C}$.

Untreated red wine grape pomace had the lowest cumulative biogas production of 93 ml and 151 ml.

Blended grapes showed a cumulative biogas production of 283 ml and 243 ml respectively. Refined red wine grape pomace generated the highest biogas production with 566 ml and 864 ml, followed by refined and cooked red wine grape pomace with a biogas production of 365 ml and 830 ml. The maximum biogas composition without CO_2 was 70% and the minimum biogas composition was 55%.

Higher fibrillation during pre-preparation as refining and or blending, and or additional heat treatment can increase the biogas production and lead to a lower retention time in the fermentation vessel due to the higher biogas production per time increment from the consumed red wine grape pomace.

Further research needs to focus on improving biomass reduction and biogas production during anaerobic fermentation.

Overall, the use of co-digestion technology by utilizing grapes pomace waste material for energy production using anaerobic fermentation could help to replace fossil fuel-based energy sources. In addition, pre-processing of feedstock could boost biogas production and most likely reduce retention time in the fermentation vessels.

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