Title: Effects of the Co-inoculation of Commercially Available Yeast and Bacteria on the Organoleptic Properties of Unaged Pot Distilled Rum

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Abstract

This project investigated the effects of co-inoculation of a commercially available yeast and three strains of lactic acid bacteria on the organoleptic properties of unaged, pot distilled rum in a commercial setting. Four production trials were performed in triplicate, with respective distillate portions aggregated: control (Lalvin EC-1118™), trial 1 (Lalvin EC-1118™ + DistilaBact® LP), trial 2 (Lalvin EC-1118™ + EnoFerm Alpha™), and trial 3 (Lalvin EC-1118™ + SafSour LP 652™). For each triplicate, a production-style spirit run was performed from low wines (85%), heads (10%), and tails (5%): control (WDC), trial 1 (WDC 1), trial 2 (WDC 2), trial 3 (WDC 3). Fermentation performance was largely unaffected by the inclusion of lactic acid bacteria, with little difference between final levels of trial pH, specific gravity, and alcohol concentration (v/v), versus the control, except trial 2, which had a significantly higher pH. Gas chromatography showed that all trials had similar concentrations of higher alcohols and esters to their respective controls, except for isobutanol and active-amyl and isoamyl alcohols, which were distinctly different for trials 2, 3, WDC 2, and WDC 3. A trained sensory panel found that each trial was distinctly different than their respective control with trial 3 having a greater overall relative score than the control (1.11 vs 0.43) and WDC 3 scoring higher than WDC (0.54 vs 0.40). The results suggest that co-inoculation fermentations using lactic acid bacteria can produce rums with improved organoleptic characteristics, without yield loss or significant additional process complexity.

Introduction

Rum is a globally produced distilled spirit, with deep historical ties to the Caribbean, and defined by CARICOM as:

1. ‘a spirit obtained exclusively by alcoholic fermentation and distillation of sugar cane molasses, sugar cane syrups, sugar cane juices or cane sugar produced during the processing of sugar cane.’
2. ‘a spirit drink distilled at an alcohol content of less than 96.0% alcohol by volume at 20°C.’
3. ‘a spirit drink produced in such a way that the product has the organoleptic characteristics derived from the natural volatile elements contained in the above raw materials or formed during the fermentation or distillation process of the named raw materials; and which includes mixtures solely of the above distillate.’(CROSQ, 2008).

Many factors play a role in the organoleptic properties of the resulting distillate including base materials and their treatment, fermentation and distillation conditions, and the maturation

program carried out by the distillery. This paper will primarily focus on molasses-based rum production, although sugarcane juice-based rums and cachaça will also be discussed. The starting point for all quality rums and cachaças begins with understanding the microbial ecology of the fermentation, primarily the yeast and bacteria driving it, since their diligent efforts are responsible for many of the organoleptic compounds found in rum: aldehydes, ketones, fatty acids, fatty acid esters, a variety of alcohols and more (Greg, 1895c; Allan, 1906; Lehtonen and Soumalainen, 1977).

The microbiology of rum fermentation and its role in product quality

The microbiology of rum fermentation and the conditions through which many of the above-mentioned organoleptic compounds are created have been studied since the 1890s (Greg, 1895a; Greg, 1895b; Greg, 1895c; Greg, 1895d; Pairault, 1903; Allan, 1906; Ashby, 1907; Ashby, 1911). From this foundation, numerous studies have furthered our understanding of the microflora present during the production of molasses/sugarcane juice-based rums and primarily found that numerous species of *Schizosaccharomyces*, *Saccharomyces*, *Bacillus*, *Clostridium*, *Propionibacterium*, *Lactobacillus*, *Leuconostoc*, and *Torulopsis* were present (Allan, 1905; Ashby, 1911; Hall et al., 1935; Shehata, 1960; Parfait and Sabin, 1975; Ganou-parfait et al., 1987; Fahrasmane et al., 1988; Ganou-Parfait et al., 1989; Fahrasmane and Ganou-Parfait, 1998; Fleet and Green, 2010). However, even with 130+ years of research, our understanding of many of the microbiological processes taking place at various production stages, remains very limited particularly when considering the resources available to beer, wine, and whisky producers (Green, 2015).

Recent developments by companies such as Lallemand and Fermentis to create useable bacteria products have justified the need for contextualizing historic and contemporary rum production techniques, specifically how the deliberate use of selected yeast and bacterial strains can lead to beneficial improvements in the organoleptic qualities of the resulting distillate, and to provide small-scale producers a proper foundation from which to approach the development of organoleptically complex rums.

Background

Rum production 1890 – 1950s

In the first decades of the 20th century as the microbiology of rum fermentation became better understood, the research community was divided, with one group (Pairault, 1903) concluding that pure fermentations using selected yeasts in an environment low in bacteria presence would lead to improved rum production and efficiency, and the other group (Allan 1905; Ashby 1909) concluding that bacteria play a major role in the organoleptic qualities of heavy rums (Fahrasmane and Ganou-Parfait, 1998). At the time, a variety of different rum styles were produced throughout Jamaica via spontaneous fermentation, with most estates offering several different marques, each being distinguished by their ester content and organoleptic characteristics (Allan, 1905; Cousins, 1907; Ashby, 1911). Before going further, it is necessary to define these historic rum styles and their fermentation/production components, which can respectively be found in **Table 1** and **Table 2**.

Table 1. Early 20th century Jamaican rum styles and descriptions.

Reference	Rum Style	Description
Cousins (1907)	Common clean	A light rum, pot distilled, with ester content 90 – 300 g/hLAA, with a principal aroma of ethyl acetate, with variation between estates due to trace amounts of other higher acid esters, traces of caprylic alcohol, and other aromatic higher alcohols.
Cousins (1907)	UK Home trade	Pot distilled rum with an ester content of 300 – 500 g/hLAA, produced from slow fermentation, characterized by a heavy residual body, mainly esters of higher molecular weight acids which originate from the large presence of bacteria in the fermentation.
Cousins (1906)	Tea rum	Pot distilled medium bodied rum with an ester content of 400 – 700 g/hLAA, primarily to enrich afternoon tea.
Cousins (1906)	Flavored/German	Produced from highly acidic fermentations, typically 15 – 21 days in length, utilizing fission yeasts, and double retort stills, with an ester content 700-1600 g/hLAA. Primarily used for rum blending.

Table 2. Early 20th century Jamaican rum fermentation components and definitions.

Reference	Item	Description
Ashby (1911)	Skimmings	The solid-liquid slurry skimmed from the surface of the sugarcane juice clarifiers, typically with a brix range of 10-20 brix.
Ashby (1911)	Dunder	Spent rum wash leftover in the still after distillation is finished. Rich in acids and typically with a brix range of 10-25 brix.
Ashby (1911)	Acid (cane vinegar)	Soured skimmings or cane juice, rich in acetic acid.
Ashby (1911)	Muck (flavor)	A liquid/sludge, rich in butyric and other higher acids, produced via a slow, controlled, putrefactive fermentation process of the liquid and solid portions of dunder, wash bottoms (dead yeast), spent stillage (low or high wines), and cane trash.

During his work in Jamaica, Ashby (1911) reported on three styles of rum production capable of yielding two versions of common clean rum (CCR1 and CCR2, with ester contents of 100 g/hLAA and 1,000 g/hLAA) and one version of the heavier bodied "flavored" rum (ester content up to 1,600 g/hLAA). Process diagrams for each style can be found in **Figure 1**. Two species of yeasts were commonly found in the fermentations (1) *Saccharomyces* spp. was most prevalent in the faster fermenting CCR1 and (2) as wash acidity and bacteria presence increased in both CCR2 and the flavored rum, *Schizosaccharomyces* spp. became dominant and fermentation time significantly increased (Allan, 1905; Ashby, 1911). Ashby (1907) reported that acetic, propionic, butyric, caprylic, capric, and lauric acids were present in rum fermentations and upon

distillation, their esters were found in rum at the following concentrations: ethyl acetate (98%), (2%) combination of butyric, caprylic, capric, lauric and other higher alcohol esters, which were found to provide body and flavor characteristics.

As seen in **Figure 1**, the reason for the significant increase in ester content is due to the complexity of the fermentation. The addition of acid and the increase in dunder further acidified the wash, which when combined with the longer fermentation time and pre-distillation rest time, allowed the necessary bacterial reactions to take place, and thus seeded the wash with copious amounts of acids and ester precursors (Allan, 1906; Ashby, 1911). Flavored rum took this further with the addition of muck, which has its own incredibly complex production method, alongside acid and dunder, to dramatically acidify the wash and lead to the production of incredibly aromatic rums with high ester contents.

Allan (1905) thought the flavored rum fermentation techniques were overly complicated and a crude attempt to foster specific strains of bacteria for acid development. Since most of the esters found in rum are formed via direct esterification, it can therefore be said that the greater the rum wash acidity, the greater the ester content in the resulting rum, however, this does not mean that all acids present in the wash will undergo esterification (Cousins, 1906; McFarlane, 1946). These acids are produced via sugar metabolism and hence why if a distiller wants to produce a “high ester” rum, the alcohol yield from that fermentation will be significantly decreased, and the bottle will justifiably command a significantly higher price (McFarlane, 1946). Additionally, many of the organic acids found in rum, either in their free state or as esters have high boiling points and are typically collected near the end of distillation and are therefore concentrated in the spent wines in the retorts (McFarlane, 1946).

Cousins developed a high ester rum production process to alleviate the efficiency losses of traditional flavored rum production and to deal with the high import tariffs of the German market (Pietrek and Smith, 2022). Scale implementation of his process allowed any estate to produce common clean variants or high ester rum without undertaking the long and complicated traditional fermentation-based approach for producing “high flavored” rum, or be forced to work with highly acidic dunder and the detrimental effects it would have on their standard rum production process (Cousins, 1906). The “Cousins Process” can be seen as a process diagram in **Figure 2**. This enabled distilleries to produce rums with ester contents up to 4,000-6,000 g/hLAA, designed for blending and were primarily used in the German market to create authentic blended Jamaican rum products to combat the rise of rum verschnitt (Cousins, 1906; Pietrek and Smith, 2022). Thirty years later, these products had significantly affected the demand for traditional Jamaican rum, and the significant backlash across the Jamaican rum industry led to the establishment of a maximum ester content of 1,600 g/hLAA (Jamaica, 1935; Pietrek, 2022).

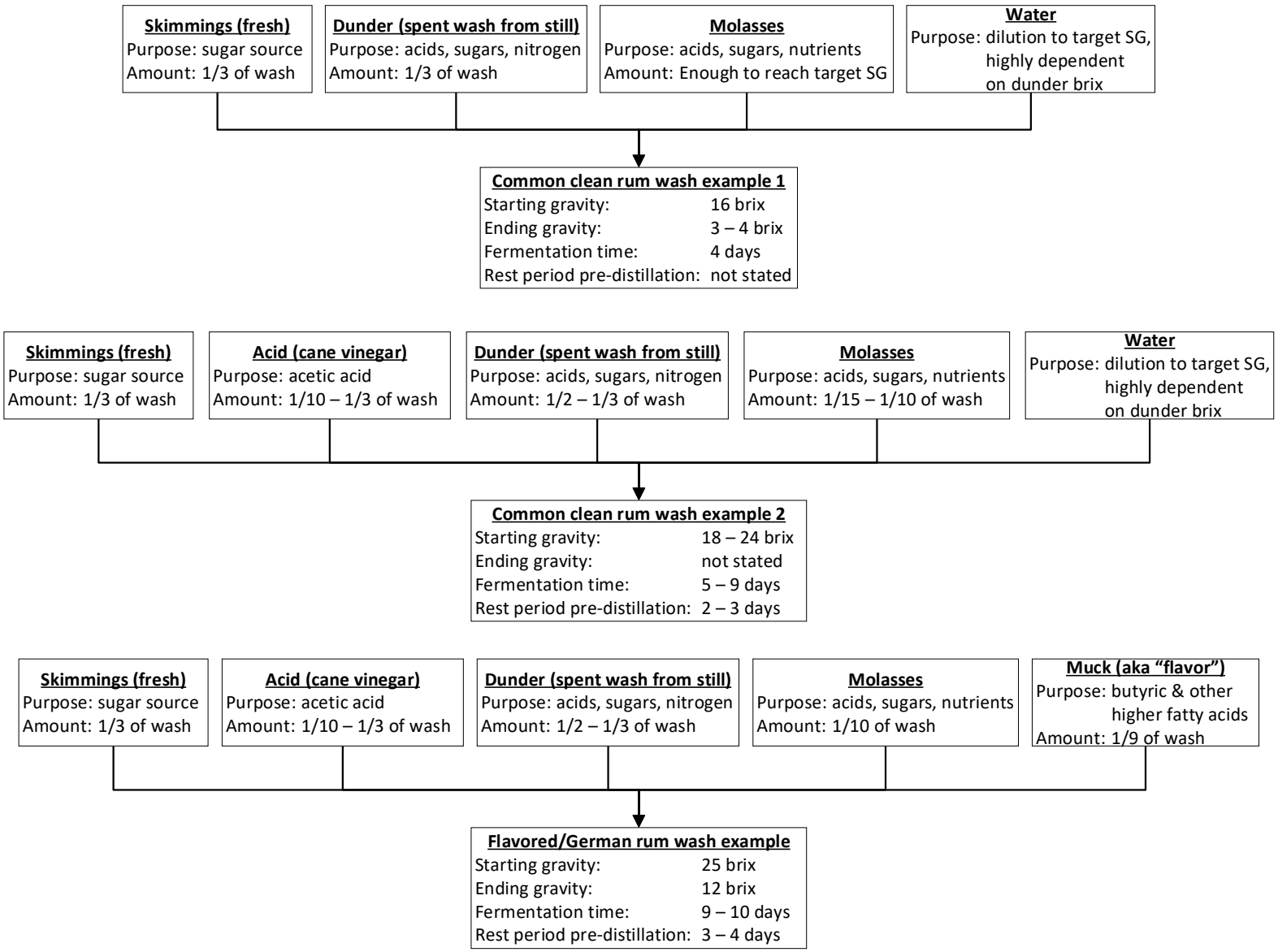

Figure 1. Fermentation process for three styles of Jamaican rum, two versions of common clean, and one version of flavored/German rum. This process diagram is based on descriptions by Ashby (1911).

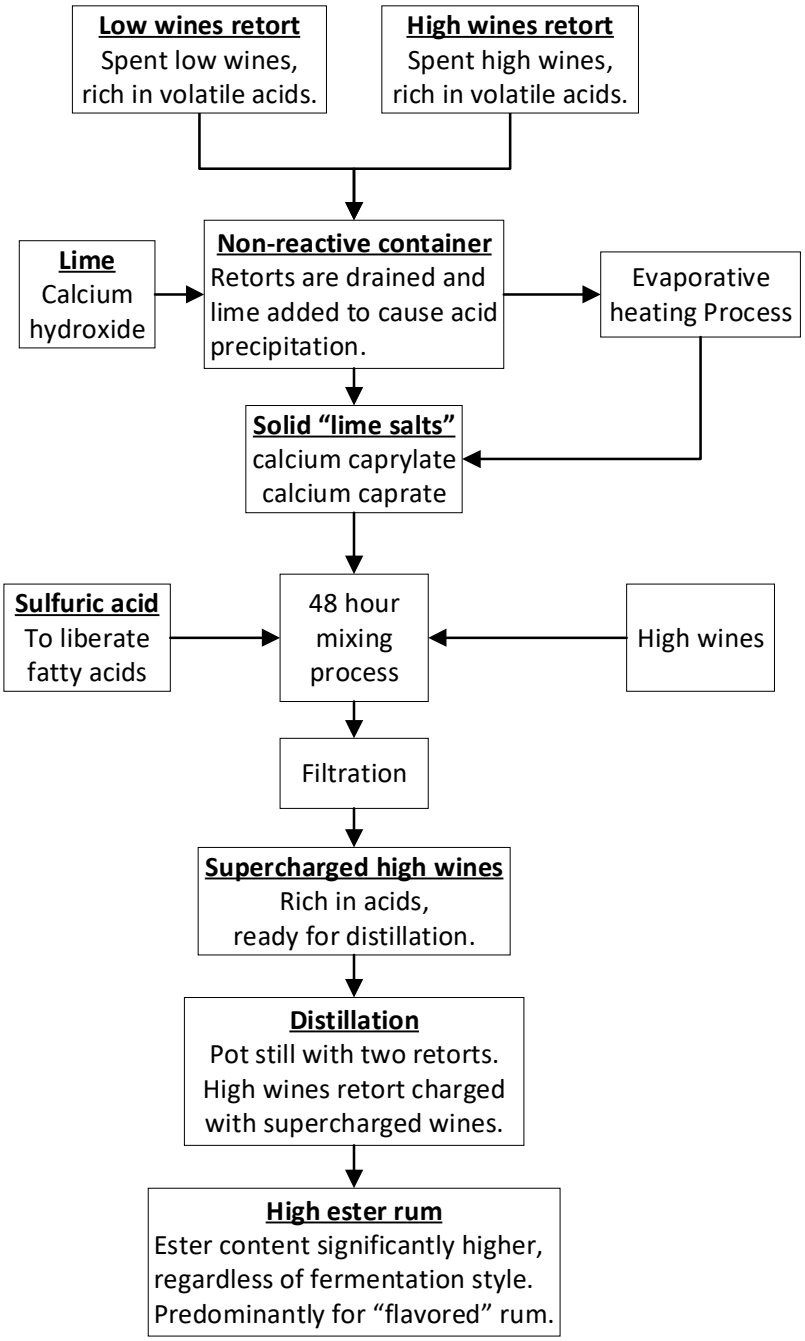

Figure 2. The legendary "Cousins Process" for producing very high ester rums used for blending. This process diagram is based on the description by Cousins (1906).

Some Caribbean distilleries followed the protocols of Pairault (1903), and used pure culture yeast strains, which lead to the production of more neutral rums, with lower levels of acids and esters, and higher amounts of higher alcohols, but most distilleries went back to using wild fermentations so as to produce more richly flavored rums regardless of production efficiency losses (McFarlane, 1946; Fahrasmane and Ganou-Parfait, 1998). In Puerto Rico throughout the 1940s, extensive investigations were conducted by Arroyo to determine commercially viable means to use cultured strains of yeast and bacteria in a controlled fermentation environment to

produce heavy rums (Arroyo, 1945a; Arroyo, 1945b). He determined that strains from the propionic acid or butyric acid bacteria groups are ideal candidates for producing heavy rums, and developed a list of specifications for selecting them (Arroyo, 1945b). In 1945, Arroyo patented his production process wherein *Schizosaccharomyces pombé Lindner* was used alongside *Clostridium saccharobutyricum* or *Propionibacterium technicum* to produce heavy rum from treated molasses, and this can be seen in **Figure 3** (Arroyo, 1945a; Arroyo, 1945b).

As of 1946, although fermentation control was found to be the most important factor in rum production, and higher pH and/or constant pH fermentations were just starting to be considered, no Jamaican rum distilleries seriously attempted to correlate wash composition with final distillate qualities or to explore the fermentation conditions where these compounds are easily produced (McFarlane, 1946). However, the Jamaican rum style classification did change to its current version and can be seen in **Table 3**. Surprisingly, by the 1950s, "production targets in organoleptic properties seemed not to have been taken into account in choosing the correct moment for modification of the fermentation stage (Fahrasmane and Ganou-Parfait, 1998)." Ultimately, economics caused many distilleries to standardize their production methods and therefore use selected pure yeast cultures in fermentation (Fahrasmane and Ganou-Parfait, 1998).

Rum production and research 1960s – present

As process standardization and the use of pure yeast cultures in fermentation became the norm, most distilleries shifted away from wild fermentation in preference of controlled fermentations, with the faster fermenting *Saccharomyces* spp. finding significantly more use than the slower fermenting *Schizosaccharomyces* spp. yeasts (Fahrasmane et al., 1988). Just in time, as consumer tastes were changing from heavier pot distilled rums towards lighter continuously distilled rums, causing many distilleries to stop producing pot distilled rums (I'Anson, 1971; Burglass, 2011). Although production styles were changing, researchers continued to investigate the microbiology of rum and cachaça production.

In Brazil, Shehata (1960) found *Saccharomyces*, *Candida*, *Pichia*, and *Torulopsis* species were prevalent on sugarcane plants and in fresh juice, however, only *Saccharomyces*, *Candida*, and *Schizosaccharomyces* species were isolated from fermenting sugarcane juice. In the French West Indies, Parfait et al. (1972), investigated the effects of *S. cerevisiae* and several non-*Saccharomyces* strains on ester production from molasses-based and synthetic mediums and found that *S. pombé* produced the greatest content of esters, and the non-*Saccharomyces* strains, *Hansenula anomala* and *Candida krusei* produced the lowest. In Martinique, where molasses-based Grand Arôme rum is produced, *S. pombé* and *Clostridium acetobutylicum* are often found during fermentation and lead to heavy rums, rich in esters (>500 g/hLAA), volatile acids (propionic, isobutyric, and butyric), and other organoleptic characteristics (Ganou-Parfait and Parfait, 1980; Fahrasmane et al., 1983; Fahrasmane and Ganou-Parfait, 1997). Fahrasmane et al. (1986), found that *S. pombé* appeared to have specific nutritional requirements which could only be found in molasses-based fermentation media and required lengthy fermentations.

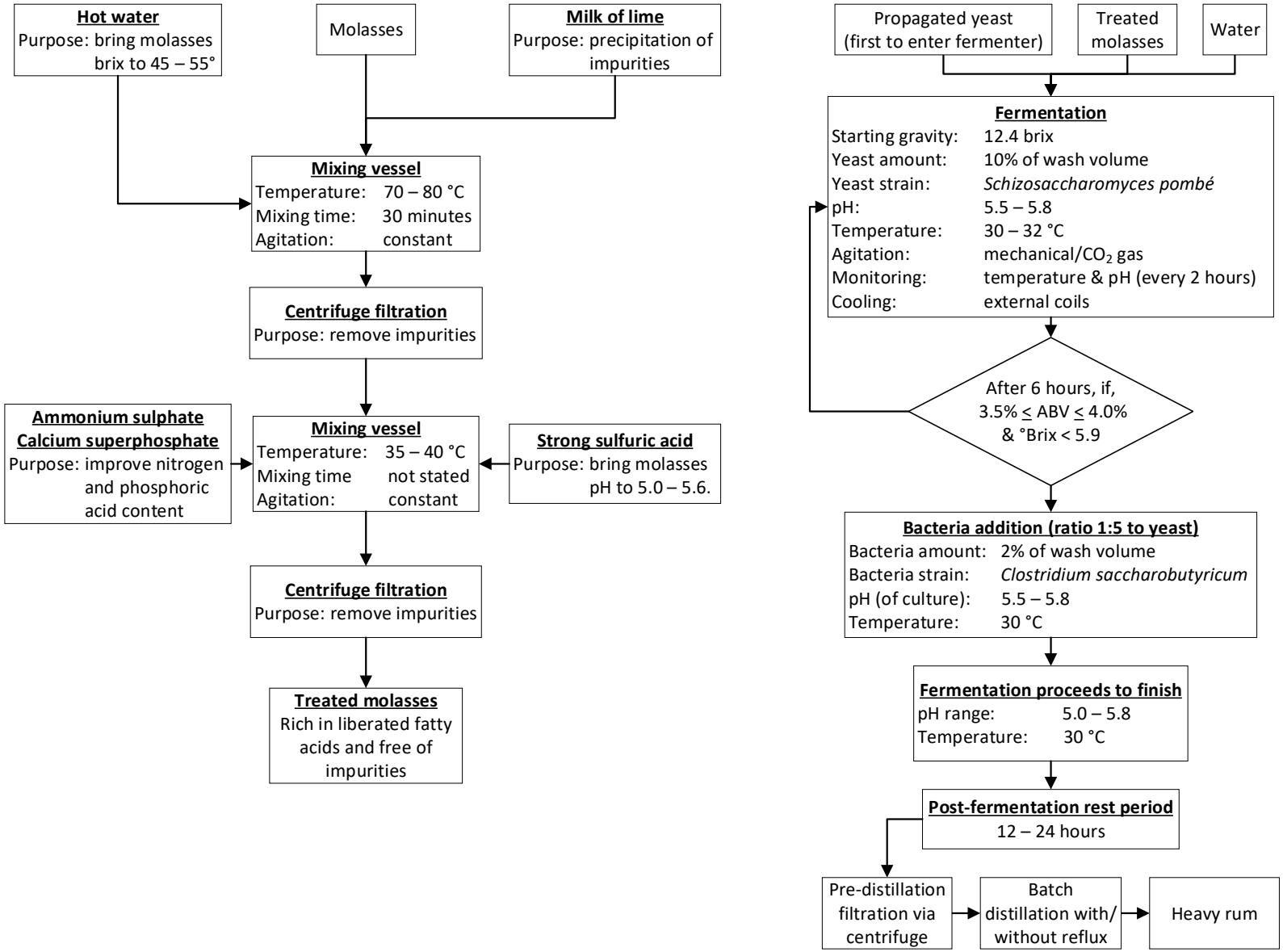

Figure 3. Process diagrams showing Arroyo's molasses treatment and heavy rum production methods. These were created based on description by Arroyo (1945b).

Table 3. Classifications of Jamaican rum styles circa 1940s, which has since become standardized.

Reference	Rum style	Ester content
McFarlane (1946)	Common clean	80 – 150 g/hLAA
McFarlane (1946)	Plummer	150 – 200 g/hLAA
McFarlane (1946)	Wedderburn	200 – 300 g/hLAA
McFarlane (1946)	Flavored	700 – 1,600 g/hLAA

From 1970-2010, much work was performed to characterize the yeasts and bacteria found in rum fermentation media and to understand how fermentation control affected their contributions to final distillate organoleptic quality. The extensive work performed by Lehtonen and Soumalainen (1977) has provided the most comprehensive analysis of rum organoleptic compounds (~200), the factors affecting their production, and the biochemical pathways leading to their formation (Green, 2015). Green (2015) has also compiled a comprehensive list. Ganou-Parfait et al. (1989), has provided a comprehensive list of 50 different bacteria species that are active during sugarcane fermentation and in which media (sugarcane juice, sugarcane syrup, or molasses) they are typically found.

Fahrasmane and Ganou-Parfait (1998) further investigated the role of bacteria in rum fermentation and their major work, showing bacteria origins, location in the production cycle, optimum temperature and pH, fermentation features, and positive and/or negative effects on fermentation and distillate quality should be the starting point for any distiller seeking to incorporate bacteria into their fermentation program(s). The microaerophilic *Lactobacillus* species and *Propionibacterium* species were found to be the most significant bacteria in rum fermentation, as the acids they produce can be esterified, and positively contribute to the organoleptic characteristics of the resulting rum (Fahrasmane and Ganou-Parfait, 1997; Fahrasmane and Ganou-Parfait, 1998).

For aromatic rum production, Lehtonen and Soumalainen (1977) recommended a fermentation temperature up to 30 °C and a pH range of 5.5-5.8, and a pH of 5.0 or greater for mixed fermentations using yeast and bacteria. Fleet and Green (2010) found several species of *Clostridium*, *Bacillus*, *Zymomonas*, lactic acid bacteria, and propionic bacteria and found that higher pH fermentation (i.e., > 5.5) offered the best chance for their contribution. However, very few studies have investigated how the combined use of selected yeast and bacteria affects the organoleptic qualities of rum.

Nemoto (1975) built on Arroyo's 1945 work and investigated two methods for producing heavy rums from molasses-based media (1) the symbiotic fermentation of *S. pombé* and *Clostridium butyricum* and (2) adding a highly acidic wash (acidified by butyric acid bacteria) to a standard rum wash fermentation prior to distillation. Symbiotic fermentation was not successful above sugar concentrations greater than 14% glucose and heavy rum could only be produced in (2) when the pH was lowered to 2.0, thus freeing the butyric acid into solution to esterify and increase the ester content of the resulting rum (Nemoto, 1975).

From 2006-2010, Green (2015) systematically investigated the microbial ecology of the molasses-based rum production process at the Bundaberg Distilling Company, Bundaberg, Australia, including the contributions of bacteria during fermentation, the microbial ecology of dunder (fresh and aged) and its effect on fermentation and rum organoleptic qualities. She conducted a series of controlled molasses-based fermentation experiments (7.5% dunder, pH 5.5, 30° Brix) using *S. cerevisiae* and the three isolated lactic acid bacteria, *Lactobacillus fermentum*, *Lactobacillus plantarum*, and *Lactobacillus* spp., in both single and mixed conditions (Green, 2015). The control (*S. cerevisiae*) fermented at a nearly constant pH (5.2-5.3), whereas the mixed fermentations experienced a significant pH drop (5.2 to 4.2-4.7) (Green, 2015). Additionally, each mixed fermentation produced significantly more ethanol than the control (6.0-7.9% vs 5.1% ABV), with the *S. cerevisiae* & *L. fermentum* trial producing significantly greater concentrations of organoleptic compounds in the fermentation and the resulting distillate (Green, 2015).

Hill et al. (2017), characterized the microbiology of dunder at a Scottish distillery, and assessed its effect on fermentation and organoleptic characteristics when added to a controlled 96-hour molasses-based fermentation. Five strains of *Lactobacillus* were isolated and identified from the dunder (Hill et al., 2017). Additionally they found that the amount of dunder added (5% of volume) was not sufficient to cause significant changes in the fermentation profile and thought that by increasing the amount added or extending the fermentation time would've allowed additional acid production or for the "symbiotic fermentation" described by Arroyo when he worked with *S. pombé* and *C. saccharobutyricum* to produce heavy rums (Arroyo, 1945b; Hill et al., 2017). However, there were significant increases in the amounts of organoleptic compounds in the resulting distillate.

In Brazil, Duarte et al. (2011), investigated the effects of co-inoculation of *S. cerevisiae* and *L. fermentum* on the quality of cachaça and found that co-inoculation yielded cachaça with higher concentrations of acetaldehyde, ethyl acetate, and 2,3-butanedione, while cachaça produced solely by the yeast had higher concentrations of ethyl lactate, propionic acid, butyric acid, and 1-pentanol. Finally, there is growing interest in using non-*Saccharomyces* yeast or a mixed inoculation with *S. cerevisiae* for cachaça production (Duarte et al., 2013; Amorim et al., 2016).

The above-mentioned studies have shown that bacteria, particularly lactic acid bacteria, play a positive role in the organoleptic properties of cachaça, rum, and whisky production, and thanks to recent technological developments by Lallemand and Fermentis, these strains can be easily used by producers to enhance the organoleptic characteristics of their spirits. This study is the first to explore their use in commercial rum production.

Project Aims

Over the summer of 2022, as part of an American Distilling Institute grant, the author investigated the effects of co-inoculation of commercially available yeast (Lalvin EC-1118™) and three bacteria (DistilaBact® LP, EnoFerm Alpha™, SafSour LP 652™) on the organoleptic properties of unaged, pot distilled rum, produced from Louisiana blackstrap molasses and raw cane sugar. The bacteria were expected to increase the quantity of specific acids during

fermentation, which the yeast would metabolize into esters and ester precursors. All work was performed around the summer production schedule at Windon Distilling Company, the home of LYON RUM, in Saint Michaels, Maryland, USA. The distillery is representative of small producers and lacks the modern laboratory equipment which allows for in-depth analysis of fermentations (i.e., plating and culturing, cell counts, microscopy, etc.) or distillates (i.e., GC-MS).

Materials & Methods

Materials

The blackstrap molasses and raw cane sugar are both non-GMO products of the Lula-Westfield Sugar Factory in Paincourtville, Louisiana, USA. The yeast and bacteria products are listed in **Table 4** and a complete list of equipment in **Table A** of the appendix.

Table 4: Yeast and bacteria products used during this project.

Product	Strain	Supplier	Description
Lalvin EC-1118™	*S. cerevisiae bayanus*	Lallemand	Popular yeast in the American distilling scene, noted for its fermentation performance, neutral sensory contribution, and ability to showcase raw ingredients.
DistilaBact® LP	*L. plantarum*	Lallemand	Lactic acid bacteria product for use in the distilling industry, capable of producing sour mash related organoleptic properties, such as lactic (creamy), citrus, and tropical fruit notes.
EnoFerm Alpha™	*Oenococcus oeni*	Lallemand	Malolactic fermentation bacteria product typically used in the wine industry to add roundness, mouthfeel, red fruit, pear, and tropical fruit notes to wines.
SafSour LP 652™	*L. plantarum*	Fermentis	Kettle-souring bacteria used in the brewing industry to add citrus, tropical, and other fruity notes to various beer styles.

Methods

Each research trial was performed in triplicate. The experimental design is shown in **Figure 4**, with each trial having an A, B, and C segment. All fermentation vessels and related equipment were cleaned and sanitized before use. The yeast and bacteria were both rehydrated and added to the fermentation according to manufacturer directions, and the trial compositions and pitch rates are stated in **Table 5**.

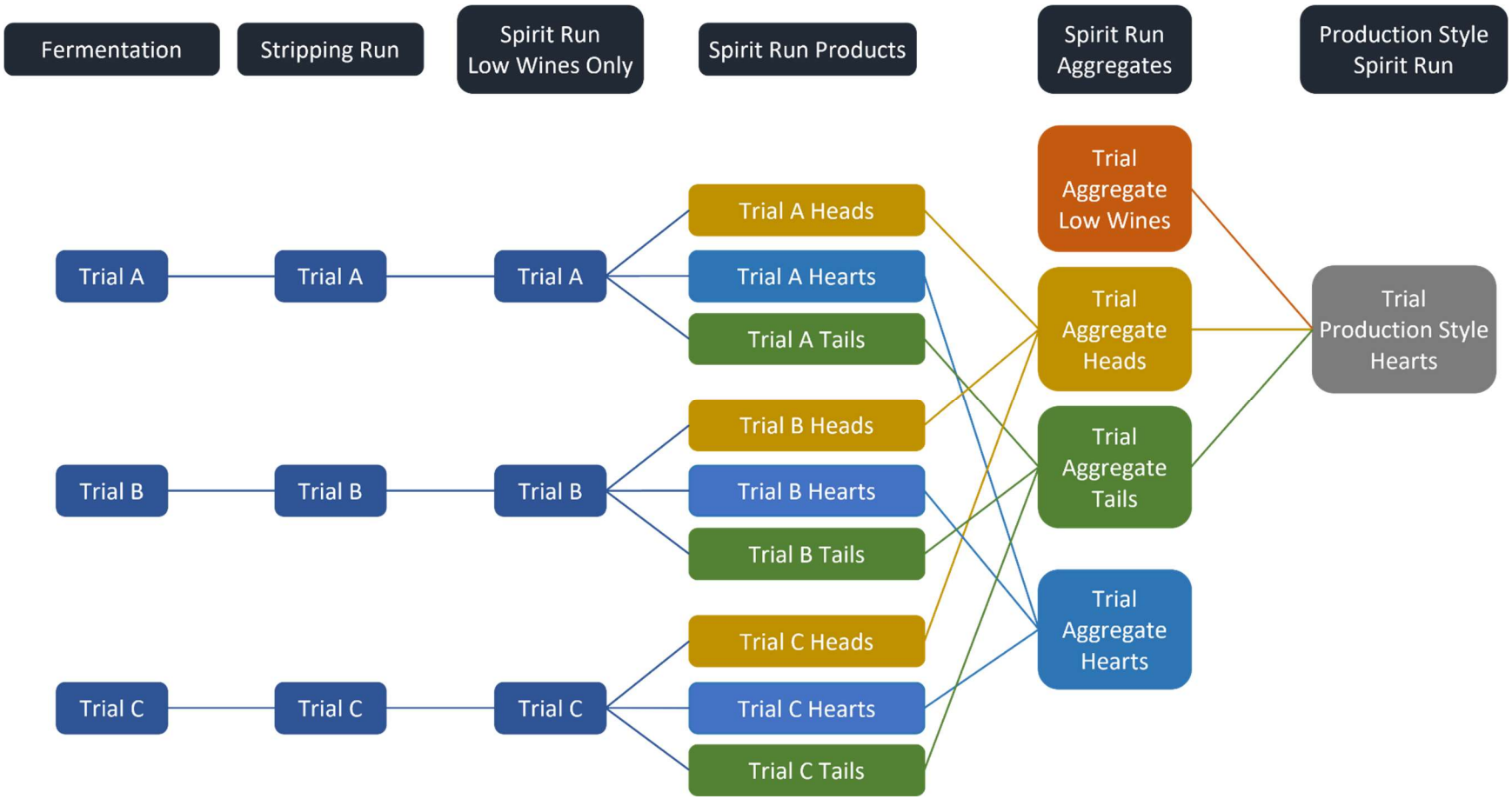

Figure 4. Project experimental design showing the composition of trial and production-style spirit runs. Each A, B, and C segment represents a complete trial triplicate. All triplicate low wines, heads, hearts, and tails were aggregated, as would be more typical in industry. This allowed a "production style" spirit run to be performed.

Table 5. Trial compositions and component pitch rates. Each trial was performed in triplicate.

Trial	Composition	Pitch rate (g/L)
Control	Lalvin EC-1118™	0.26
1	Lalvin EC-1118™ + DistilaBact® LP	0.26 | 0.1
2	Lalvin EC-1118™ + EnoFerm Alpha™	0.26 | 0.01
3	Lalvin EC-1118™ + SafSour LP 652™	0.26 | 0.1

Fermentation performance was tracked with a standard glass fermentation hydrometer and an Oakton pH meter (calibrated weekly in pH 7 and pH 4 solutions, and properly stored between uses). For stripping runs, a standard glass distillation hydrometer was used to track starting and ending alcohol concentration (Percent alcohol by volume; %ABV). During fermentation, daily measurements were taken for specific gravity, pH, and temperature, including a visual/sensory check of activity. Fermentation was complete when there was no change in specific gravity within a 24-hour period and no fermentation activity was visually present.

Fermentation

Each fermentation was 76 L with a composition of 10.89 kg blackstrap molasses, 9.07 kg raw cane sugar, and 62.78 kg filtered municipal water. The target fermentation temperature was 30 °C, to aid in ester development. The molasses and sugar were weighed into the fermentation vessel and then heated water (31-34 °C) was added. Then, each fermentation was thoroughly mixed using a commercial immersion blender before yeast and bacteria additions. The setup for weighing ingredients and heating the water is shown in **Figure 5**. Trial 2 had different temperature requirements than the others and the water for this trial was heated to 29 °C, to ensure a pitch temperature below 30 °C, and that the fermentation temperature would drop below 27 °C when the fermentation was ~10% ABV. All fermentations took place in lidded 208 L stainless steel drums and were completed after 144-163 hours, with an average wash strength of 10.84% ABV.

Figure 5. Equipment setup for weighing fermentation ingredients and heating the water.

Distillation

Stripping runs were performed in 100 L pot stills, heated by an internal electric element (**Figure 6**). Once heated, the stills operated at 11 amps (out of 20) for an average of 8.4 hours. Low wines were collected into glass carboys and had initial and final alcohol concentrations of 66% ABV and 16% ABV, respectively, with an average yield of 15.14 L at 42% ABV per run.

Spirit runs were performed on an 11.36L (US 3 gallon) still, heated by an electric hot plate (**Figure 7**). Once heated, the still operated at a heat setting of 4.5 (out of 5.0). Two sets of spirit runs were performed, and the distillates for each set had the same cut points and collected volumes. Additionally, the still, onion head, lyne arm, and worm tub condenser were rinsed multiple times with hot water and dried between uses. The first set was distilled entirely from low wines and will be referred to as **control**, **trial 1**, **trial 2**, and **trial 3**. For each triplicate, the heads, hearts, tails, and remaining low wines were blended to create respective aggregates. The second set was a "production style" spirit run using a ratio of low wines (85%), heads (10%), and tails (5%), 11.36 L in total, and will be referred to as control (**WDC**), trial 1 (**WDC 1**), trial 2 (**WDC 2**), trial 3 (**WDC 3**). The hearts were then slowly proofed to 45% ABV using carbon filtered municipal water, as is standard practice at Windon Distilling Company. The choice of 45% ABV was not arbitrary and served as a point of comparison to our standard white rum, which is also produced from a champagne-style yeast and bottled at 45% ABV.

Figure 6. The 100 L stills that were used for stripping runs, showing controllers and the carboys used for low wines collection.

Figure 7. The 11.36 L (3 US gallon) alembic pot still and hot plate used for all spirit runs.

Data analysis

For each trial, samples were taken from the proofed aggregate hearts and brought to Brewing and Distilling Analytical Services (BDAS Testing, https://bdastesting.com) in Lexington, Kentucky, USA, for gas chromatography and sensory panel analysis. The services are detailed in **Table 6**. After testing the data was analyzed using Microsoft Excel.

Table 6: BDAS testing services utilized for this project.

Testing service	Description
CP09: Distilled Spirits Comprehensive Chemical Profile	Alcohol % By Volume and Weight, Acidity (Volatile and Total), Haze, Higher Alcohols and Esters via GC, pH, and Residual Extracts/Total Solids.
CP11: Taste panel evaluation	Single evaluations and multi-time/date evaluations offered. A full 36 attribute descriptive sensory profile with radar (spider) charts, bar charts, and sensory summary.

Results

Fermentation results

Fermentation performance was largely unaffected, with little difference between final levels of trial pH, specific gravity, and %ABV, versus the control, except for trial 2, which had significantly higher pH (**Table 7** and **Figures 8-11**). Fermentation length varied between 144-163 hours and was found to be significantly different for trial 1 and trial 3 compared to control (144 hours vs 163 hours). No differences were found in fermentation length for trial 2 (163 hours).

375 **Table 7. Trial fermentation data showing triplicate averages and standard deviations for each factor.**

Trial	Hours	Temperature (°C)	Specific Gravity	pH	%ABV
Control	0	31.6 ± 0.2	1.092 ± 0.000	5.81 ± 0.01	00.00 ± 0.00
	24	30.4 ± 0.2	1.083 ± 0.000	5.35 ± 0.01	01.37 ± 0.00
	48	30.1 ± 0.2	1.058 ± 0.001	5.23 ± 0.01	05.09 ± 0.14
	72	29.5 ± 0.3	1.043 ± 0.000	5.04 ± 0.11	07.17 ± 0.00
	96	29.4 ± 0.2	1.031 ± 0.000	4.77 ± 0.23	08.82 ± 0.00
	120	28.5 ± 0.2	1.020 ± 0.001	4.57 ± 0.26	10.35 ± 0.13
	144	27.9 ± 0.2	1.017 ± 0.000	4.48 ± 0.23	10.74 ± 0.06
	163	27.0 ± 0.1	1.014 ± 0.000	4.43 ± 0.23	11.10 ± 0.00
Trial 1	0	32.6 ± 0.1	1.090 ± 0.000	5.90 ± 0.00	00.00 ± 0.00
	24	33.8 ± 0.6	1.080 ± 0.003	5.27 ± 0.00	01.46 ± 0.39
	48	33.3 ± 1.6	1.055 ± 0.000	4.98 ± 0.05	05.12 ± 0.07
	72	32.7 ± 0.5	1.034 ± 0.002	4.67 ± 0.18	08.11 ± 0.21
	96	31.0 ± 0.5	1.023 ± 0.001	4.53 ± 0.21	09.63 ± 0.17
	120	30.3 ± 0.3	1.014 ± 0.001	4.44 ± 0.22	10.74 ± 0.12
	144	29.8 ± 0.1	1.014 ± 0.001	4.41 ± 0.20	10.74 ± 0.12
Trial 2	0	27.8 ± 0.0	1.090 ± 0.000	5.80 ± 0.00	00.00 ± 0.00
	24	31.4 ± 0.2	1.084 ± 0.000	5.32 ± 0.00	00.91 ± 0.00
	48	31.8 ± 0.2	1.059 ± 0.001	5.16 ± 0.00	04.55 ± 0.14
	72	31.3 ± 0.3	1.045 ± 0.001	5.09 ± 0.00	06.58 ± 0.11
	96	29.6 ± 0.2	1.032 ± 0.001	5.05 ± 0.01	08.42 ± 0.13
	120	28.3 ± 0.1	1.023 ± 0.000	5.02 ± 0.04	09.59 ± 0.00
	144	28.1 ± 0.0	1.017 ± 0.000	4.98 ± 0.08	10.38 ± 0.00
	163	27.8 ± 0.1	1.014 ± 0.000	4.95 ± 0.10	10.74 ± 0.06
Trial 3	0	32.2 ± 0.2	1.092 ± 0.000	5.80 ± 0.00	00.00 ± 0.00
	24	31.4 ± 0.2	1.080 ± 0.000	5.22 ± 0.01	01.82 ± 0.00
	48	31.2 ± 0.2	1.057 ± 0.001	5.00 ± 0.00	05.19 ± 0.11
	72	30.2 ± 0.3	1.040 ± 0.002	4.79 ± 0.07	07.63 ± 0.26
	96	29.7 ± 0.3	1.025 ± 0.002	4.61 ± 0.12	09.63 ± 0.22
	120	28.5 ± 0.2	1.018 ± 0.001	4.48 ± 0.12	10.61 ± 0.12
	144	28.4 ± 0.2	1.016 ± 0.001	4.40 ± 0.09	10.79 ± 0.12

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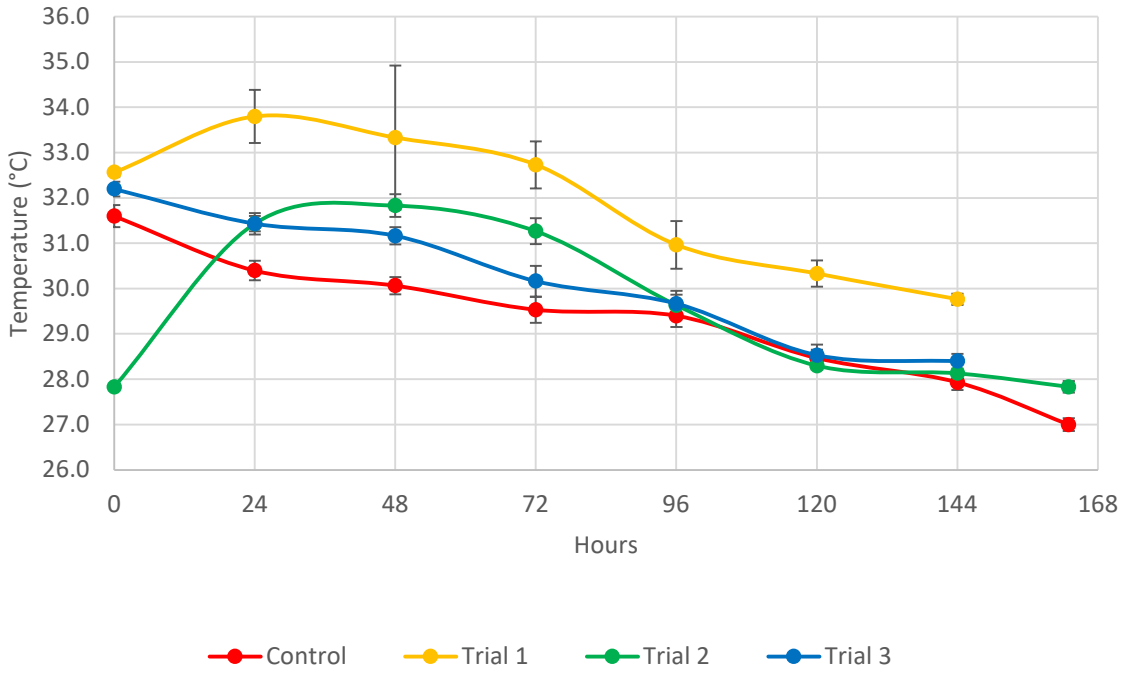

Figure 8. Trial fermentation temperature. Each data point and associated error bar represents the trial triplicate average and standard deviation.

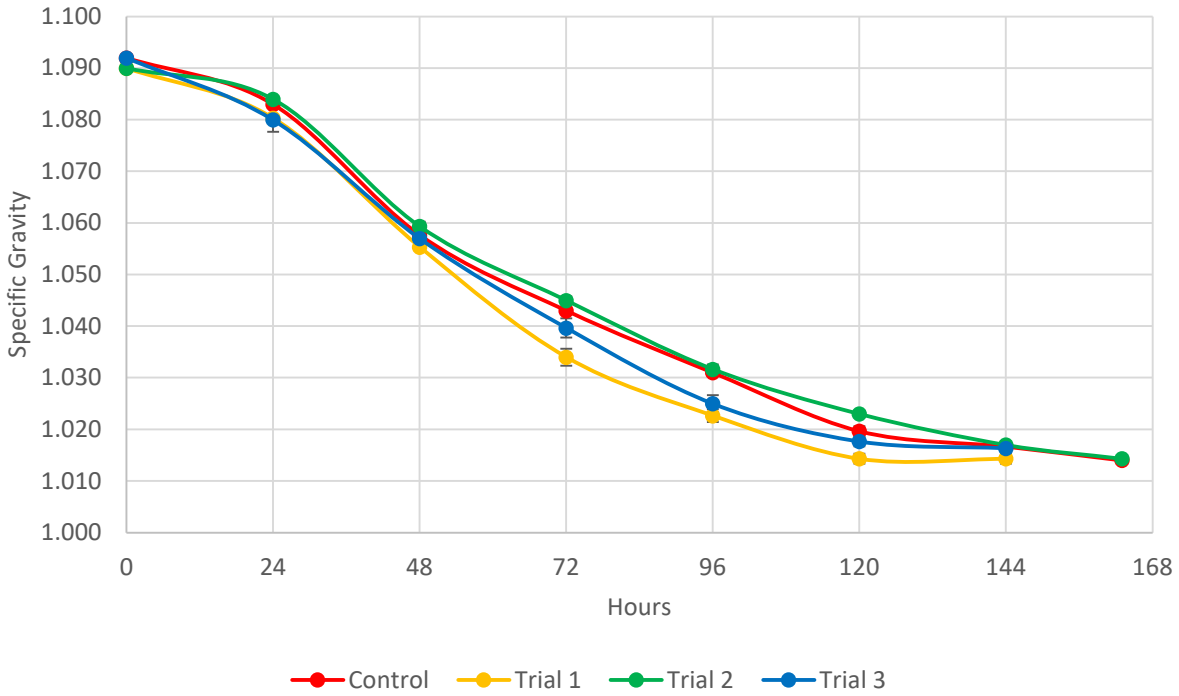

Figure 9. Trial fermentation performance averages for specific gravity. Each data point and associated error bar represents the trial triplicate average and standard deviation.

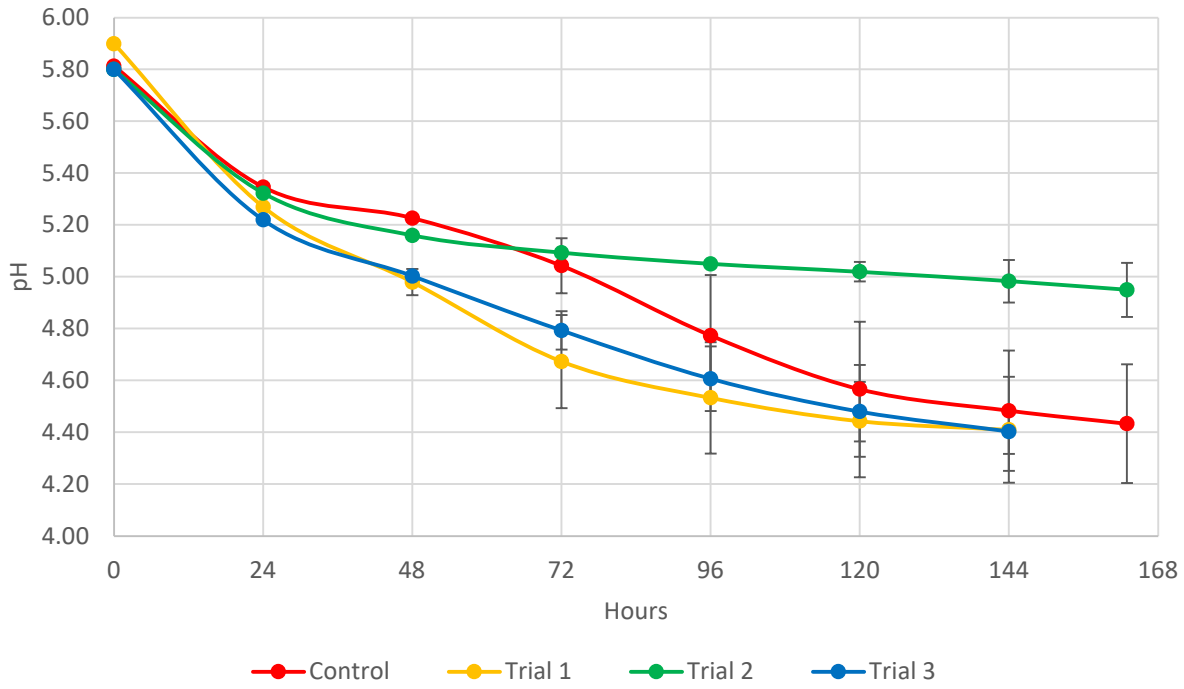

Figure 10. Trial fermentation performance averages for pH. Each data point and associated error bar represents the trial triplicate average and standard deviation.

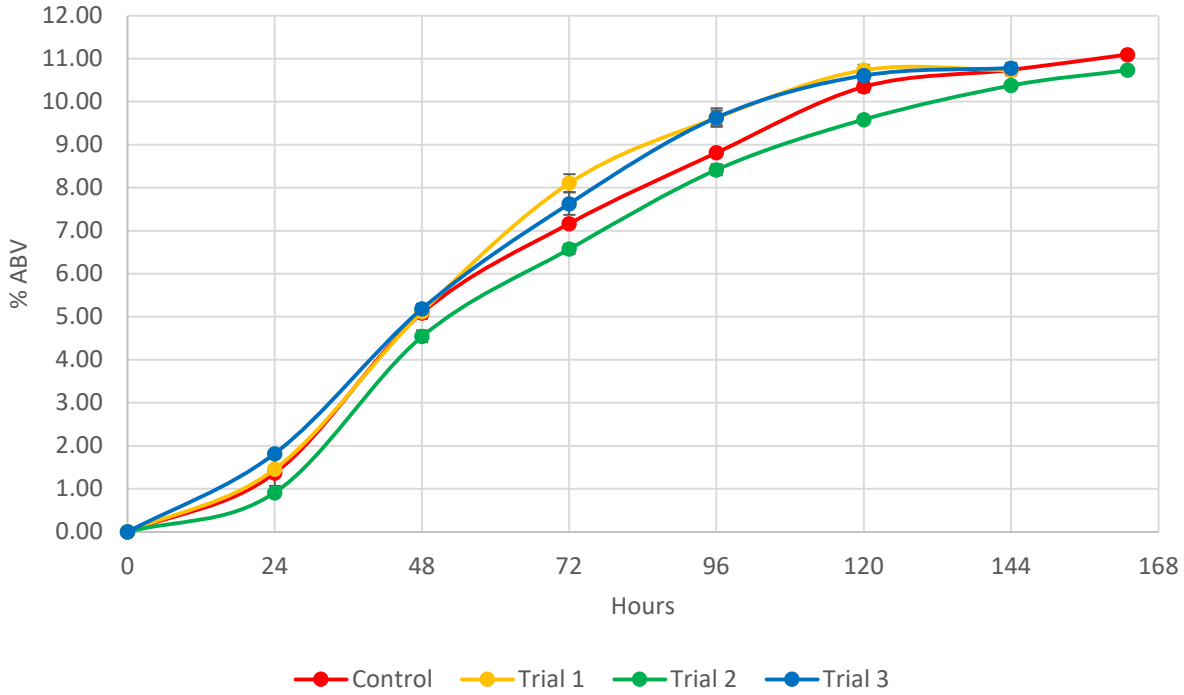

Figure 11. Trial fermentation performance averages for alcohol concentration (v/v). Each data point and associated error bar represents the trial triplicate average and standard deviation.

Gas chromatography and sensory panel results

All trials had similar concentrations of higher alcohols and esters to their respective controls, except for isobutanol and active amyl and iso-amyl alcohols, which were distinctly different for trials 1, 2, WDC 1, and WDC 2. Additionally, the total fusel oil content, which is the sum of n-Propanol, Isobutanol, 1-Butanol, and active amyl and iso-amyl alcohols, was distinctly different in trials 1-3, WDC 1 and WDC 2 (**Table 8** and **Figure 12**).

A trained sensory panel evaluated all distillates using a 36-point attribute ballot (**Table 9**). Each trial was found to be distinctly different than their respective control with trial 2 having a greater overall score than the control (1.11 vs 0.43) and WDC 3 scoring higher than WDC (0.54 vs 0.40) (**Figure 13** and **Figure 14**, respectively). BDAS testing states on their sensory panel results that, "A consistently well produced spirit beverage with little to fault it and one appropriate to intended style, class, or type, and at its best, fresh release, would potentially earn a score of between 1.0- 2.0 and a zero score represents a sample with little to fault but nothing to note.". The investigator self-assessed each distillate set and found them to be distinctly different than their respective controls, with trial 1 preferable to the control and WDC 1 preferable to WDC (**Table 10**).

Table 8. Gas chromatography results for each trial showing the concentrations of compounds detected. Ester and higher alcohol concentrations were determined in accordance with the SSD:TM:200 testing method. Total fusel oils represent the sum of n-Propanol, Isobutanol, 1-Butanol, and Active amyl and iso-amyl alcohols. Compound threshold values from Hill (2023): acetaldehyde (8.1 ppm), ethyl acetate (16.8 ppm), n-propanol (7.8 ppm), isobutanol (6.5 ppm), 1-butanol (5 ppm), isoamyl alcohol (5-10 ppm), furfural (30 – 230 ppm).

	Control	Trial 1	Trial 2	Trial 3	WDC	WDC 1	WDC 2	WDC 3
Acetaldehyde (ppm)	17.85	13.14	25.10	17.94	29.24	25.68	45.42	27.27
Ethyl acetate (ppm)	83.44	85.89	96.69	81.91	119.57	108.71	129.67	131.87
Methanol (ppm)	13.75	12.81	12.74	15.22	13.29	12.26	11.01	14.29
n-Propanol (ppm)	245.37	231.32	206.66	232.35	233.52	224.74	196.33	225.86
Isobutanol (ppm)	521.91	644.08	655.27	519.73	516.41	649.12	642.31	520.65
1-Butanol (ppm)	1.14	0.91	0.56	0.91	1.10	1.08	0.69	1.02
Active amyl and Iso-amyl alcohols (ppm)	1527.34	1472.95	1751.77	1452.06	1295.7	1295.47	1516.14	1265.66
Furfural (ppm)	2.93	2.78	1.23	1.55	1.59	1.72	0.94	0.8
Total fusel oils (ppm)	2295.77	2349.27	2614.26	2205.06	2046.73	2170.42	2355.47	2013.19

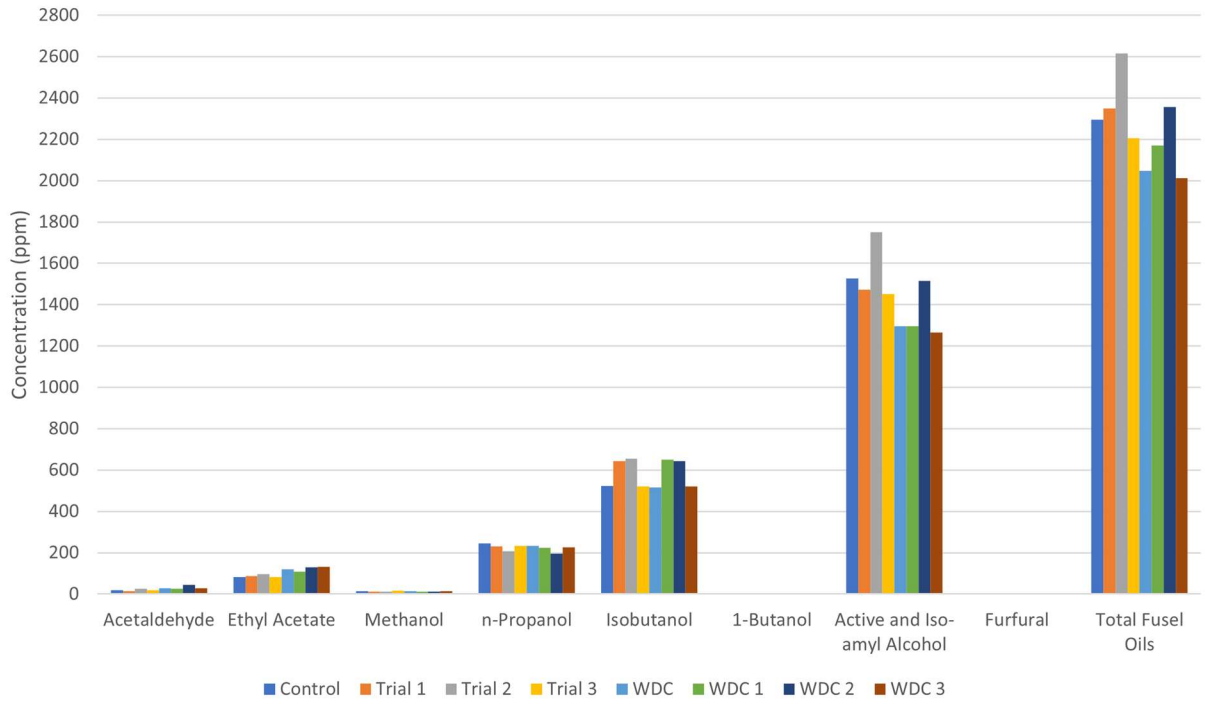

Figure 12. Gas chromatography results for each trial showing compound concentrations. Note: total fusel oils represent the sum of n-Propanol, Isobutanol, 1-Butanol, and Active amyl and iso-amyl alcohols.

Table 9. Sensory panel evaluation results from BDAS Testing in Lexington, Kentucky, USA. All values represent the average panel scores for each parameter. Bold values indicate (1) trial values greater than the control or (2) control values greater than trials.

Sample ID/Parameter	Control	Trial 1	Trial 2	Trial 3	WDC	WDC 1	WDC 2	WDC 3
Overall Score	0.43	**0.68**	**1.11**	0.40	0.40	0.29	-0.21	**0.54**
Aroma	0.43	**0.64**	**0.96**	**0.57**	**0.93**	-0.07	0.64	0.11
Flavorful	0.71	0.43	**0.86**	0.50	**0.64**	0.50	-0.07	0.43
Flabby-Complex	0.57	0.50	**0.86**	0.43	0.00	-0.07	-0.29	**0.73**
Harsh-Smooth	-1.00	**0.41**	**0.71**	**0.79**	-1.00	**0.21**	**0.43**	**0.93**
Oxidation	-0.14	-0.29	**0.29**	**0.14**	-0.71	**0.29**	**0.71**	**0.29**
Sweet	1.04	0.89	**1.29**	0.87	0.73	**0.87**	**0.79**	**1.07**
Dry	**0.57**	0.29	0.29	0.29	0.71	**0.86**	0.71	**0.57**
Astringent/Drying	**0.43**	0.14	0.00	0.00	0.02	0.00	**0.43**	0.00
Viscosity	1.14	0.93	**1.32**	0.79	0.57	**0.71**	**0.86**	**0.71**
Metallic	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Alcoholic	1.57	1.50	**1.86**	**1.71**	**2.86**	2.14	2.29	2.21
Solventy	**1.43**	0.86	0.43	1.00	1.00	0.57	**1.29**	0.71
Fruity	**1.29**	0.43	0.43	0.43	0.71	**0.75**	0.36	**0.93**
Higher Alcohol/Fusel	**1.36**	0.46	0.50	0.87	1.07	**1.16**	1.07	0.87
Molasses	**1.00**	0.57	0.86	0.30	0.73	0.59	0.73	0.59
Caramel	**0.71**	0.43	0.71	0.29	**0.57**	0.14	0.21	0.36
Toasty	0.36	0.30	**0.71**	0.54	0.02	**0.30**	**0.09**	**0.59**
Vanilla	**0.79**	0.57	0.61	0.46	0.16	0.16	0.01	**0.44**
Clove like/Spicy	**0.50**	0.14	0.32	0.14	0.29	0.14	0.29	0.00
Aromatics	**0.29**	0.02	0.04	0.02	0.02	**0.04**	**0.14**	0.01
Smoky	0.14	**0.29**	0.14	0.14	**0.29**	0.00	0.14	0.14
Burnt/Roasted	0.00	0.00	**0.14**	0.00	0.00	0.00	0.00	0.00
SO2/Burnt Match	**0.29**	0.14	0.14	0.29	0.29	0.29	0.29	0.14
H2S/Rotten Egg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rubbery	0.29	0.14	0.29	**0.43**	0.29	0.00	0.29	0.00
Bad yeast	**0.43**	0.00	0.00	0.00	**0.29**	0.00	0.00	0.00
Papery/Cardboard	0.00	0.00	0.00	**0.14**	0.00	**0.14**	**0.43**	0.00
Bready/Stale	0.07	0.00	0.00	**0.14**	0.29	0.14	**0.57**	0.14
Acetaldehyde	0.00	0.00	0.00	0.00	**0.29**	0.00	0.00	0.14
Oak	0.00	0.00	0.00	0.00	**0.29**	0.02	0.01	0.14
Woody/Nutty	0.14	**0.16**	**0.45**	**0.30**	**0.29**	0.02	0.01	0.07
Diacetyl	0.00	**0.29**	**0.29**	**0.29**	**0.32**	0.14	0.00	0.00
Phenolic/Medicinal	**0.43**	0.14	0.14	0.14	0.29	0.00	**0.86**	0.00
Moldy/Musty/Earthy	**0.43**	0.02	0.14	0.16	**0.29**	0.02	0.01	0.00
Tart/Acetic/Sour	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.14**
Grassy/Hay-like	0.00	0.00	0.00	0.00	**0.43**	0.29	0.00	0.00

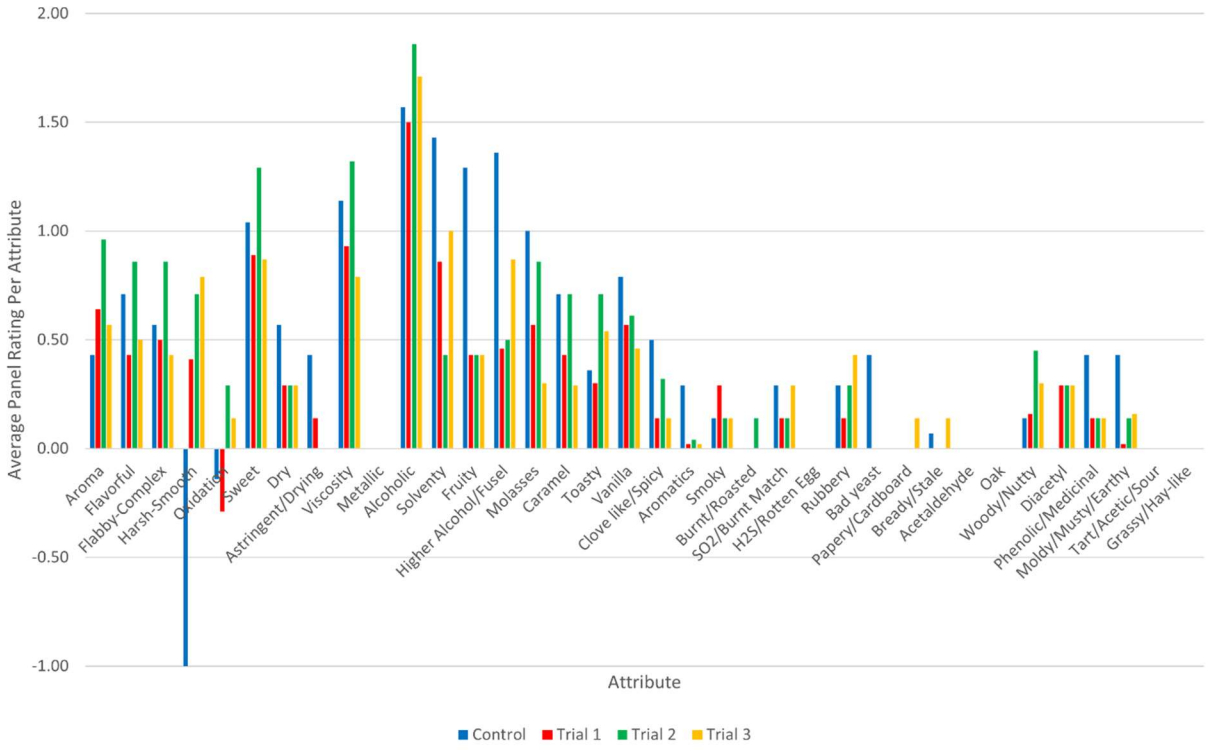

Figure 13. Sensory panel results showing the average attribute score for the low-wines-only distillates. The overall scores were – control 0.43, trial 1 0.68, trial 2 1.11, and trial 3 0.40.

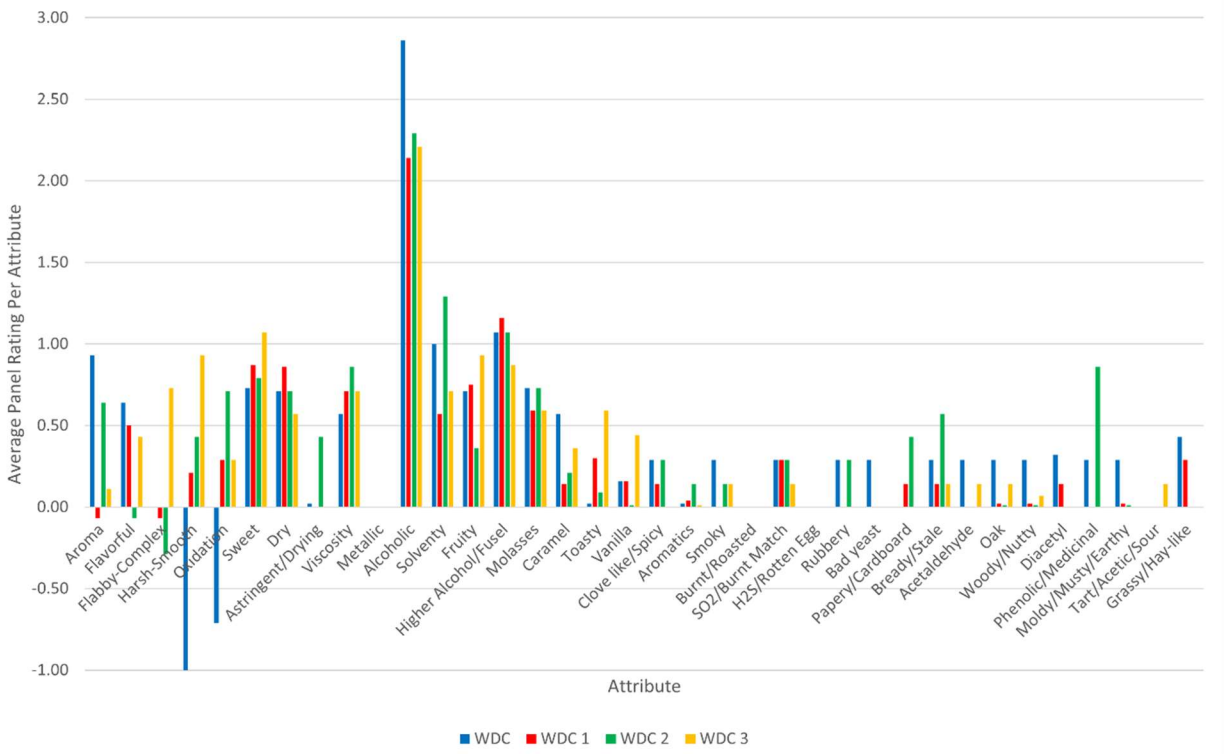

Figure 14. Sensory panel results showing the average attribute score for the production-style distillates. The overall scores were – WDC 0.40, WDC 1 0.29, WDC 2 -0.21, WDC 3 0.54.

433 **Table 10: Self-assessment sensory notes for low-wines-only and production-style distillate samples.**

Trial	Self-assessment notes	Trial	Self-assessment notes
Control	Nose Neutral, but with hints of molasses and grass, and very slight notes of phenols	WDC	Nose Creamy, grassy, with hints of custard cream and vegetal notes, and alcohol presence.
	Palate Creamy profile and mouthfeel, with hints of grassy/herbaceous notes and a very, very faint phenol presence.		Palate Very creamy and grassy! Coconut crème, grass, with alcohol presence and a shorter finish.
Trial 1	Nose Citrus and tropical fruit notes on top of a grassy and coconut crème mid note and a gentle floral and molasses base note.	WDC 1	Nose Incredible nose! Very good balance of creamy, grassy, citrus, and tropical notes.
	Palate More complex than Lalvin EC-1118™, with tropical fruit and citrus, grass, coconut crème. No phenolic notes. Long, delightful finish.		Palate Very much like the nose. Great balance of creamy, grassy, citrus, and tropical notes. Long creamy, grassy, tropical finish! This would continue to develop in barrel and be a perfect candidate for a cognac cask.
Trial 2	Nose Creamy, floral, red apple and peel notes, gentle molasses aromas, faint grass, and alcohol vapors.	WDC 2	Nose Very different than the above two WDC samples. More apple/red apple, pear, grass, and spices. There is an unpleasant phenol off-aroma that comes through.
	Palate Molasses/coconut crème, grassy, floral with red fruit notes, apples, and a long, layered finish.		Palate Somewhat flatter, with a not too pleasant phenolic note. Alcohol presence isn't balanced. Finish is long but not complex. Burns.
Trial 3	Nose Grassy, with coconut crème, alcohol, faint molasses, and hints of tropical and citrus fruits.	WDC 3	Nose Bigger and bolder than the other SafSour sample, with significantly more citrus and tropical creamy notes, mild alcohol presence with a grassy, coconut crème complex.
	Palate Grassy with coconut crème notes, citrus, and tropical fruits, bright and very creamy, hints of almonds and slightly floral.		Palate Less well combined than the nose. Mostly alcohol, with hints of citrus, tropical flavors, coconut crème and grass. Barrel aging would improve.
Ranking	Trial 1, trial 3, trial 2, control	Ranking	WDC 1, WDC, WDC 3, WDC 2

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Discussion

Fermentation

Except for trial 2 pH, all trials had similar fermentation performance to the control, including yield (control 11.10 %ABV vs trials 10.74-10.79 %ABV). This is noteworthy since the deliberate use of bacteria in fermentation can be detrimental to overall performance and yield however, these modern bacteria products have mostly demonstrated a beneficial ability to work with this selected yeast strain to produce rum with unique characteristics. During visual inspections, each co-inoculation fermentation had a better fermenting appearance than the control and this may be due to the added bacteria strains dominating other strains present in the fermentation media. Both the DistilaBact® LP and SafSour LP 652™ were developed specifically for the distilling industry and functioned as expected. However, EnoFerm Alpha™ was developed specifically for the wine industry, and its lower pitch temperature, along with other temperature conditions, may have affected the yeast performance during fermentation leading to off-note development.

Although yields weren't dramatically affected, off-notes were detected by the sensory panel, and there are many potential factors for this. Lack of temperature control (**Figure 8**) may have played a role in the presence of several off-notes found by the sensory panel, particularly for trial 2, where fermentation temperatures were above 27 °C when the fermentation was ~10% ABV. It was surprising to see how EnoFerm Alpha™ affected the fermentation pH. It was expected that the pH would have dropped similarly to the other bacteria trials, however, it stalled at just under pH 5.0. The fermentation composition could have played a role in buffering the effects of the bacteria. Had time allowed, it may have been best to wait a day between fermentation being confirmed as "complete" to allow the bacteria more time to work, as was suggested by others (Allan, 1905; Ashby, 1911; Pietrek and Smith, 2022).

Distillation

This project took place around the summer production schedule of LYON RUM which meant that all distillations were performed on weekends and two stripping runs needed to happen on Saturdays. Since each run required at least 8.4 hours, lack of distilling time is why the low wines were not collected down to 5% ABV as is more typical at the distillery. Therefore, the cut points for both stripping and spirit runs likely played a role in the concentrations of compounds found in the distillates. Many of the acid-based esters come over late in the distillation and one reason the effects of the selected bacteria were not more pronounced is likely due to the cut points. McFarlane (1946) found this to be true and the primary reason for the success of the Cousins Process as these acids are typically concentrated in the retorts. The addition of heads and tails also played a role in the final distillate organoleptic qualities, and for WDC 2, may have added compounds that later resulted in the significant phenolic off-notes present in the distillate. The decision to use in-house pot stills for distillation instead of a column still or a pot still with several plates, played a major role in final distillate quality, since the greater reflux of the latter still types could make it more difficult to distinguish the beneficial organoleptic effects of the bacteria. Additionally, the worm tub condenser (**Figure 7**) may have added perceived fault notes as these types of condensers are known to maintain sulfur notes and produce heavier spirits that benefit from longer maturation.

Sensory impact

In general, all distillates exceeded respective compound threshold values except for 1-butanol and furfural (**Table 8**). Compared to their respective control, each bacteria had distinct effects on distillate organoleptic characteristics – isobutanol and active amyl and iso-amyl alcohols concentrations for trial 1, trial 2, WDC 1, WDC 2, and total fusel oil concentration for trial 2, WDC 1, and WDC 2 – and echoes the findings of Duarte et al. (2011) and Green (2015) that co-inoculation of *S. cerevisiae* and *L. fermentum* or *L. plantarum* in sugarcane-based fermentation media can produce distillates with enhanced organoleptic characteristics and compound concentrations.

Sensory panel results (**Table 9**, **Figure 13**) show that the trials had lower average scores than the control, specifically: harshness, dryness, astringent/drying, stale, phenolic, and musty/earthy. However, the control had greater average scores for solventy, fruity, higher alcohol/fusel (surprising), molasses, vanilla, clove-like/spicy, aromatic. For all other attributes, at least one of the trials had the same or greater average score than the control. For the production-style distillates (**Table 9**, **Figure 14**), WDC was found to have more fault notes than the trials, specifically: harshness, oxidation, bad yeast, smokiness, and moldy/musty/earthiness. Additionally, WDC had greater scores for aroma, flavorful, alcoholic, caramel, acetaldehyde, oak (surprising since it's not matured), woody/nutty, diacetyl, and grassy/hay like. For all other attributes, at least one of the trials had the same or greater average score than the control.

It was quite surprising that the overall scores for the production-style distillates were lower than the low-wines-only distillates. This was most significant for WDC 2 compared to trial 2 (-0.21 vs 1.11), with the former containing noticeable phenolic off-notes. This suggests the amounts of heads and tails negatively affected distillate quality. For both distillate sets, the sensory panel preferred at least one trial to their respective control (trial 1, trial 2, and WDC 3 each scoring higher). Overall impressions suggest that each bacteria adds significant roundness and fruity/sweet notes to the distillates. During self-assessment, this presented as tropical/citrus notes, with enhanced creaminess on the profile. Low wines and heads, hearts, and tails cut points likely played a role in the organoleptic qualities of each distillate. Process refinement would improve these qualities and reduce the presence of off-notes, as would maturation and the beneficial effects of oak and air contact.

Conclusions and future work

This project has shown that co-inoculation fermentations are capable of increasing product organoleptic characteristics, without significant process complexity or yield loss. These results are from one-shot trials with a champagne-style yeast, *S. cerevisiae bayanus*, noted for its neutral effects on the resulting distillate. With continued process refinement, and focusing on a single bacteria product, the presence of off-notes would be significantly reduced.

Future work should focus on (1) the effects of cut points, and heads and tails additions on final distillate quality; (2) determining the ideal spirit run cut points for each bacterial product to best showcase their effects on final distillate quality. The latter case could be accomplished by first determining cut points for the control and then, repeating these exactly for the first trial, with

subsequent trials modifying the heads and tails cuts. Then, if desired, “production style” distillate trials would be similarly performed, with trials varying the amounts of heads and tails added, to further determine their effects on final distillate organoleptic quality. Changing the yeast strain or using multiple yeasts in concert with these novel bacterial products, could yield remarkably complex rums. Maturation also plays a significant role in spirit quality and can improve the harsh/unpleasant characteristics of new make distillates through the numerous reactions taking place within the barrel over time and thus transform it into excellent aged spirit. Therefore, if time and budget allow, performing the above future work as part of a longitudinal study, would show the effects of maturation on the resulting distillates over time, and yield commercially actionable data on the utility of these bacteria products.

It is imperative that distilleries and suppliers continue to openly communicate, discuss, develop, and trial novel bacteria products, or yeast-bacteria combination products. It’s truly an exciting time to be a distiller! In the near future, suppliers could offer “starters” which would be combinations of yeast and bacteria, tailored to provide specific profiles from a particular raw ingredient base and/or beverage category. And when that day comes, the industry will have come full circle to considerations made by Greg (1895d), Pairault (1903); Allan (1905), Ashby (1909), and countless others over 100 years ago. Except this time, we will be able to select specific strains of bacteria and yeast that can work together to create rums with specific profiles brought about through fermentation control, understanding of fermentation microbiology, timing for bacteria addition, and the effects that distillation cut points have on the concentration of compounds found in the rum. Clearly there is much work to be done in this area and this research topic is wide open for those researchers intrepid enough to make their mark.

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Appendix

Table A. Complete list of equipment used during this project, including their associated costs.

Item	Model / Type	Brand	Website	Quantity	Unit Cost	Total
RV water filter	KDF/Carbon filter	Camco	https://www.amazon.com/Camco-TastePURE-Flexible-Protector-40043/dp/B0006IX87S/ref=sr_1_5?crid=150PB8AWQIMJC&keywords=camco+water+filter&qid=1681663726&sprefix=camco+%2Caps%2C143&sr=8-5	1	$ 16.66	$ 16.66
Stainless steel drum with lid	55-gallon	Bubba's Barrels	https://www.bubbasbarrels.com/55-gallon-open-head-drum-20-gauge	3	$ 523.00	$ 1,569.00
Stainless steel stock pot with lid	80 Qt	Vigor	https://www.webstaurantstore.com/vigor-80-qt-heavy-duty-stainless-steel-aluminum-clad-stock-pot-with-cover/473SSPOT80.html	2	$ 189.93	$ 379.86
Induction cooktop, portable	208 – 240 V, 3500 W	Avantco	https://www.webstaurantstore.com/avantco-ic3500-countertop-induction-range-cooker-208-240v-3500w/177IC3500.html	2	$ 208.62	$ 417.24
Table stove	120 V, 900 W	Oster	https://www.amazon.com/Oster-CKSTSB100-B-2NP-Adjustable-Temperature-Control/dp/B0082JMCB6	1	$ 60.00	$ 60.00
Immersion blender	1.25 HP, 14" shaft	Avamix	https://www.webstaurantstore.com/avamix-ibhd14-14-heavy-duty-variable-speed-immersion-blender-1-1-4-hp/928IBHD14.html	1	$ 349.99	$ 349.99
Platform scale	650 lbs x 0.25 lbs	Global Industrial	https://www.globalindustrial.com/p/industrial-bench-floor-scale-660-lb-x-0-25-lb	1	$ 300.95	$ 300.95
Digital scale	500g x 0.01g	Brifit	https://www.amazon.com/Upgraded-Digital-Kitchen-Back-Lit-Included/dp/B08DXWFZLZ?th=1	1	$ 11.99	$ 11.99
Fermentation hydrometer	Specific gravity	Northern Brewer	https://www.northernbrewer.com/products/beer-and-wine-triple-scale-hydrometer	1	$ 7.99	$ 7.99
Alcohol hydrometer	%ABV & Proof	Brewer's Supply Group	https://www.amazon.com/Proof-Tralle-Hydrometer-200/dp/B01C7MRFYW/ref=sr_1_3?crid=19A7X4EDXSCED&keywords=bsg+hydrometer&qid=1681662064&sprefix=bsg+hydrometer%2Caps%2C162&sr=8-3	1	$ 14.95	$ 14.95
Thermometer	CDT300	Comark	https://www.amazon.com/Comark-Instruments-PDT300-Waterproof-Thermometer/dp/B001U59MDA/ref=sr_1_8?crid=1UPF69FHBZF56&keywords=comark+cdt+300&qid=1681660992&s=home-garden&sprefix=comark+cdt+300%2Cgarden%2C110&sr=1-8	1	$ 27.75	$ 27.75
Electronic alcohol meter	Snap 41	Anton-Paar	https://www.anton-paar.com/corp-en/products/details/snap/	1	$1,803.00	$ 1,803.00
pH Meter with calibration & storage liquids	pHTester® 50	Oakton	https://www.coleparmer.com/i/oakton-phtestr-50-waterproof-pocket-ph-tester-premium-50-series/3563415	1	$ 240.07	$ 240.07
Graduated cylinder	1,000 mL	Pyrex	https://www.coleparmer.com/i/pyrex-3025-1l-cylinder-brand-3025-graduated-1000-ml/3454627	1	$ 112.50	$ 112.50
Graduated cylinder	100 mL	Pyrex	https://www.coleparmer.com/i/pyrex-3025-100-brand-graduated-cylinder-100-ml/3454604	1	$ 43.00	$ 43.00
Glass jar	32 fl oz	Mason	https://www.amazon.com/Ball-Mouth-Quart-Mason-Bands/dp/B07MZ8ZKSR/ref=sr_1_4?crid=2C2D46TKVGG3D&keywords=mason+jar&qid=1681663850&sprefix=mason+jar%2Caps%2C1067&sr=8-4	4	$ 11.95	$ 47.80
Glass jar	12 fl oz	Mason	https://www.amazon.com/Ball-Regular-Mouth-Mason-2-Pack/dp/B07MZCXCV4/ref=sr_1_11?crid=2C2D46TKVGG3D&keywords=mason+jar&qid=1681663850&sprefix=mason+jar%2Caps%2C1067&sr=8-11	2	$ 8.50	$ 17.00
Glass jar	112 fl oz	IKEA	https://www.ikea.com/us/en/p/ikea-365-jar-with-lid-glass-plastic-s19277767/	8	$ 9.99	$ 79.92
Pot still	26-gallon	Hillbilly Stills	https://www.hillbillystills.com/store/26-Gallon-Boiler-p322064814	3	$1,400.00	$ 4,200.00
Pot still	3-gallon	Al-Ambiq	https://www.copper-alembic.com/en/traditional-riveted-alembic-stills/10-l-traditional-riveted-alembic-still	1	$ 172.69	$ 172.69
Glass carboy	5-gallon	North Mountain Supply	https://www.amazon.com/gp/product/B09B4FMMPH/ref=ppx_yo_dt_b_search_asin_title?ie=UTF8&psc=1	8	$ 53.65	$ 429.20
Glass carboy	3-gallon	Geo Sports Bottles	https://www.amazon.com/gp/product/B074Q35J1Y/ref=ppx_od_dt_b_asin_title_s00?ie=UTF8&psc=1	8	$ 49.99	$ 399.92
					Total	$10,701.48