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SHORT COMMUNICATIONS

Production of prototype lab-scale oak barrel analogues using additive manufacturing

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ABSTRACT

Experiments involving the maturation of wine or spirits in oak barrels are economically challenging to undertake, especially when there is a need for extensive replication to account for the compositional variability of oak wood. Barrel maturation is also difficult to emulate at a laboratory-scale due to the significant increase in surface-area to volume ratio when working with smaller barrel formats. Cost-effective methods that provide a semi-permeable environment for oxygen transfer and modelling of barrel maturation environments while maintaining a more realistic surface area to volume ratio would therefore be valuable for researchers.

This preliminary research study investigated a novel use of additive manufacturing (3D printing) to fabricate cost-effective laboratory-scale maturation vessels that required less volume to fill but still achieved a surface-area-to-volume ratio of oak contact closer to that of a conventionally sized barrel.

Experimental vessels and 28-L commercial casks were filled in replicate with grape distillate and aged for two years. Vessels were weighed at the completion of maturation to ascertain evaporative losses, and extraction was measured using colour absorbance at 430 nm. Seventy eight percent of the experimentally produced vessels successfully held maturing spirit for the duration of a two-year maturation study. The vessels showed statistically significant improvements in the ratio of evaporation and extraction (both $p < 0.0001$) when compared to small format 28-L commercially sourced casks and accepted industry values for more common 200–300-L casks.

KEYWORDS: barrel maturation, 3D printing, distillation, spirits, brandy

INTRODUCTION

Performing laboratory-scale maturation experiments intended to mimic the characteristics of commercial-scale barrel ageing is a unique challenge for oxidatively matured beverages such as brown spirits (brandy, rum, whisky) or fortified wines. For these experiments, there are currently few cost-effective options that accurately simulate the extraction and evaporation conditions experienced during commercial-scale (200–600-L) barrel maturation.

Although practical for accelerated maturation studies, the use of small format barrels (1–5-L) means that the ratio ($\frac{Surface-area}{Volume}$) of wood contact (surface-area, *s*) to liquid (volume, *v*), as well as evaporation rate, can be vastly in excess of that typically observed in commercial 200–220-L barrels (Del Toro Del Toro *et al.*, 2023; Hughes & Hughes, 2012). This can lead to the over-extraction of oak components and imposes an upper limit on the length of experiments due to the accelerated evaporation. As such, small barrel formats have been found to be unsuitable as an experimental model (Jeffery & Berglund, 2016; Withers *et al.*, 1995).

"Pilot" barrels that account for the surface area to volume ratio of normal barrels have been developed by research organisations working with spirits, such as the Bureau National Interprofessionnel du Cognac (BNIC). Their design consists of a 2-L stainless-steel tube sealed at both ends with oak discs ($\frac{S}{V}$ ~7.5 m^{-1}) held in place by stainless-steel bolts and flanges (Snakkers *et al.*, 2003). Pilot vessels are often designed to be fabricated in stainless-steel as they are strong, relatively inert, and resistant to corrosion. While Snakkers *et al.* (2003) suggested that their design was viable for experimental replication, the cost of stainless-steel pilot barrels (AU$300–500 per vessel) is significant, especially when a high number of replicates is required.

Considering the needs and challenges, the emerging field of additive manufacturing offers a potential solution for development of a research-scale maturation vessel. Additive manufacturing (AM), more colloquially referred to as 3D printing, is a cost-effective, flexible and fast tool for rapid prototyping and small batch manufacturing of objects from a 3D digital model (Alimi & Meijboom, 2021; Schneider & Gärtner, 2022). AM has grown in popularity in recent years, primarily due to decreased costs of printing equipment, leading to the emergence of consumer-grade machines and a lower barrier of entry for everyday use by a broader range of users than specialist fabricators (Tully & Meloni, 2020). The two most common types of printers currently available are fused deposition modelling (FDM) and stereolithography (SLA). FDM printers fuse plastic filament extruded through a fine (typically sub 1 mm) nozzle, one layer at a time. A wide variety of filament types are available to suit the needs of the user, and the printed objects typically require minimal post-print processing (*e.g.*, sanding, washing, support material removal). In contrast, SLA printers precisely deposit whole layers of ultra-violet curable resin at a time, improving speed and precision of prints. However, this style of printing requires significant post-print processing and has issues with high levels of volatile organic compounds released during production.

Using an FDM printer, this study sought to fit wide-necked glass laboratory bottles (*i.e.* Schott bottles with a GLS 80 thread) with custom-made 3D printed caps designed to hold oak disc inserts, to develop a novel, cost-effective solution for barrel maturation of beverages on a laboratory-scale. The evaporation and extraction rates of these prototype vessels were measured at the conclusion of 2-year maturation trials, to compare performance against commercial barrels (200–600-L).

MATERIALS AND METHODS

1. Materials

One-litre round, GLS 80 thread, flint glass (clear) bottles from both Pyrex (Rowe Scientific Lonsdale, SA, Australia) and Duran (Sigma-Aldrich, Castle Hill, NSW, Australia) were used in the laboratory-scale barrel analogue (LSBA) design. The plastic pouring lip accompanying the purchased bottles was removed. PolyLite acrylonitrile butadiene styrene (ABS) filament was sourced from Polymaker (Changshu City, P.R.C.). Seasoned American oak headboard staves (23 mm thick) were sourced from AP John Cooperage (Tanunda, SA, Australia). Silicone gaskets (6 mm thick, 76 mm OD, 64 mm ID) were sourced from Industrial Gaskets (Melrose Park, SA, Australia). Clarified beeswax was sourced from Adelaide Beekeeping Supplies (Richmond, SA, Australia).



FIGURE 1. 3D representation of the *laboratory-scale barrel analogue* (LSBA) design, comprising a GLS 80 bottle, silicone gaskets, ABS (acrylonitrile butadiene styrene) cap, oak disc and spanner.

2. 3D Computer-Aided Design (CAD) models

The 3D modelling was conducted using the Fusion 360 software package (ver 2.0.17457, Autodesk, San Francisco, USA). An existing design of a GLS 80 bottle and cap was sourced from the GrabCAD repository (GrabCAD, 2016) and used for further modifications. The cap was extended by ~24 mm to allow room for an oak insert and changed to a hex-nut external finish to facilitate tightening of the caps (Figure 1). A spanner matching the hex-nut was also designed to allow easy tightening and loosening of the seals. The models were designed to be printable without supports, improving the surface finish and dimensional accuracy

of the cap threads. A copy of the CAD models used are included in the supplemental materials and shared under creative commons license (CC BY-NC-SA 4.0 Attribution-NonCommercial-ShareAlike 4.0 International).

3. 3D Printing

The 3D print files were exported to the printer, an UpBox+ (Beijing Tiertime Technology Co., Ltd, Beijing, P.R.C.) and printed in ABS 1.75 mm, 0.15 mm layer height, with 80 % infill. Printer and filament settings were consistent with manufacturer specification for the PolyLite ABS, the nozzle temperature was set at 260 °C, the bed temperature was 100 °C, the print speed at 40 mm/s, and cooling fans were disabled on the extruder. Support brackets for the LSBAs were printed in ABS, so weight bearing was on the glass bottles and not the caps once they were placed on wine bottle racks (IKEA, Adelaide Airport, SA, Australia) for storage.

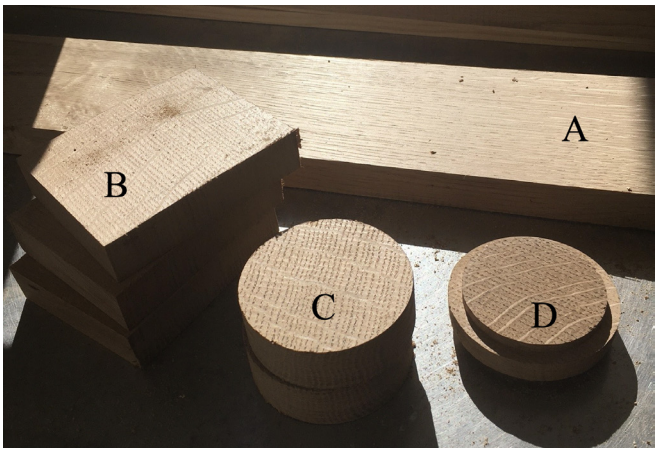


FIGURE 2. Stages of oak disc fabrication showing (A) headboard staves, (B) ~90 mm sectioned blocks, (C) ~77 mm oak disc, and (D) discs with 6.0 mm × 6.35 mm rebate.

4. Oak disc preparation

Seasoned American oak headboard staves (Figure 2A) were trimmed to ~90 mm wide blocks (Figure 2B). A 3.25-inch (83 mm external diameter, ~77 mm internal diameter) hole saw (30052-52L, Lenox Tools, East Longmeadow, MA, USA) was used without the centre bit to cut 77 mm oak discs (Figure 2C) from the blocks using a drill press and vice. Discs were then rebated 6 mm deep on both sides (Figure 2D) using a 0.25-inch (6.35 mm) rebating bit (T 1708 B, Carbitool, Moorabbin, Vic., Australia) on a router table.

The oak discs were toasted on an IEC CH2092-001 thermostat-controlled hotplate (Industrial Equipment & Control Pty. Ltd., Thornbury, Vic., Australia) set at 200 °C for 20 minutes (Figure 3A). A stainless-steel cover plate for the hotplate was custom fabricated (Figure 3A) (Ackland Stainless Steel, Thebarton, SA, Australia) for toasting of the discs to ensure even surface contact. A surface mount Type K thermocouple (6 mm diameter, RS Pro, Smithfield, NSW, Australia) was mounted to the edge of the cover plate to monitor the toasting interface temperature. A Stanley IR

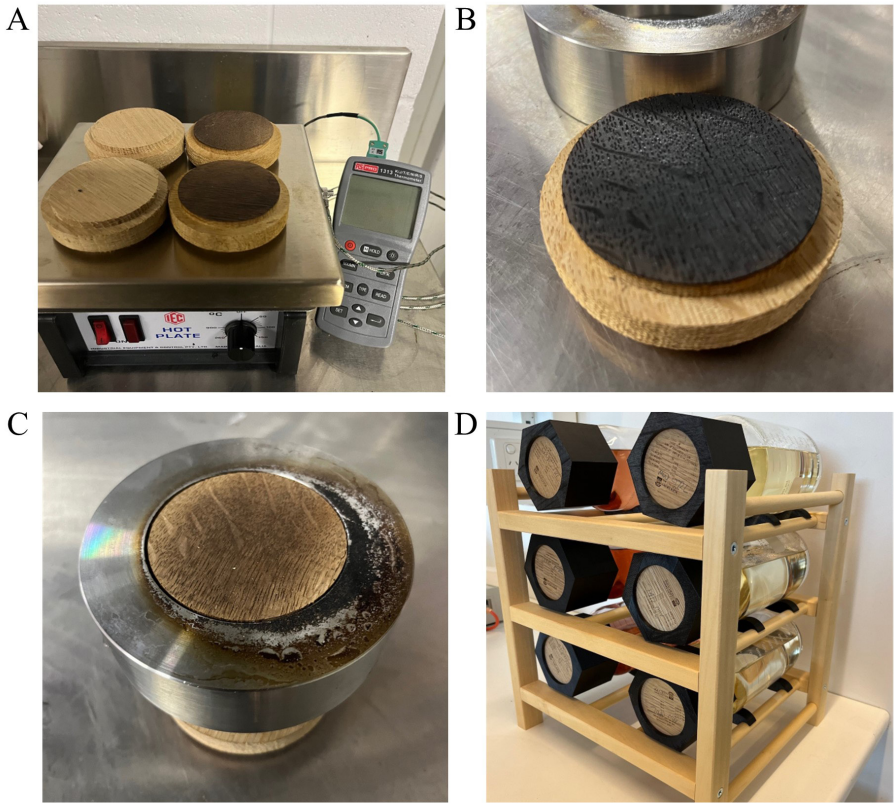


FIGURE 3. (A) Hotplate with stainless cover and thermocouple (un-toasted discs on the left, toasted on the right), (B) disc post-charring with heatshield removed, (C) oak disc charring process showing oak disc and heatshield, and (D) LSBAs on storage racks with support brackets underneath each.

Thermometer (Bunnings, Mile End, SA, Australia) was used to verify the surface temperatures of the discs while toasting. The discs were labelled using the laser engraving head of a Snapmaker Original (Snapmaker, Shenzen, Guandong, P.R.C.).

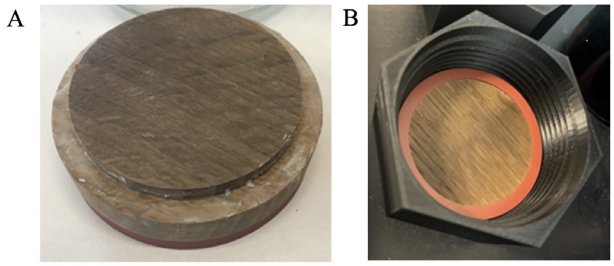


FIGURE 4. Details of oak discs showing (A) sealing rebate with wax layer and (B) cap with interior silicone gasket.

Charred discs (#1 char, Figure 3B) were prepared from pre-toasted discs using a MasterPro butane torch (Minimax, Adelaide, SA, Australia) with grades of char (#1–4) evaluated visually against a reference chart (Independent Stave Company, 2024). A stainless-steel heat shield was also fabricated (Plastico Hackett Engineering, Torrensville, SA, Australia) to protect the 6 mm rebate (sealing area) from degradation during the charring process (Figure 3C). A CAD design of the heatshield is included in the supplemental materials.

A thin layer of beeswax was applied to the surface of the rebate on the wetted side (Figure 4A). Silicone gaskets were fitted on the rebates on both sides of the oak disc (Figure 1; Figure 4B).

5. Maturation trials

Eighteen 1-L LSBAs were filled with 1 L of 55 % alcohol by volume grape spirit and matured using toasted (n = 9) and toasted and charred oak caps (n = 9). For comparison, 28-L French oak barrels consisting of "Alcohol + Toast" - toasted (n = 6) and "Vanilla Toast" - toasted and charred (#1 char) (n = 6) were sourced from Seguin Moreau (Wingfield, SA, Australia) and filled with the same spirit. The toasted disc LSBAs were intended to emulate the "Alcohol + Toast" casks and the toasted and charred disc LSBAs were intended to emulate the "Vanilla Toast" casks. The maturation trials were performed as part of experiments comparing the production of brandy from three different varieties, Sauvignon blanc, Shiraz (Syrah) and Pinot noir sourced from the Adelaide Hills wine region during vintage 2020. The selection of cooperage (two treatments) and the wine varieties (three conditions) were the basis for the six experimental conditions used in these studies. Experimental conditions for the 1-L LSBAs were filled in triplicate, while the 28-L Seguin Moreau casks were filled in duplicate. The wines were vinified and distilled according to standard practices employed for Cognac style spirits (Léauté, 1990), with a single 1-tonne ferment conducted for each variety and the base wines double distilled in a 700-L copper pot still. The only exception to standard practice was that the red varieties were fermented on skins, before being pressed prior to distillation.

Once filled the maturation vessels (28-L barrels and the 1-L LSBAs) were stored in a dark bond store without temperature control; the maturation environment experienced a maximum temperature of 26 °C and 64.5 % relative humidity for the duration of the maturation trial. The LSBAs and 28-L barrels were weighed and sampled at the conclusion of the two-year maturation.

6. Laboratory analysis

The LSBAs were weighed using a Kern EW 4200-2NM precision balance (Sigma-Aldrich Castle Hill, NSW, Australia) to establish evaporative losses. Colour (yellow/brown) of matured spirit was measured (in triplicate) at 430 nm with reverse osmosis water as a reference (Duncan & Philp, 1966; Harrison, 2023; Pryde *et al.*, 2011) using a Shimadzu UV-1280 UV-Visible spectrophotometer (Shimadzu Scientific Instruments Pty Ltd, North Plympton, SA, Australia). Absorbance at 430 nm was used as a proxy measure for the extractive potential of the oak discs. The pH of the spirits was measured (in triplicate) using an Ohaus Starter 3100 pH meter (Ohaus Oceania, Vic., Australia).

7. Statistical analysis

Statistical analyses of the evaporation and absorbance data were undertaken using analysis of variance (ANOVA) with XLSTAT Sensory Edition (v 2023.2.1414) software package. Factors were base wine varietal "*variety*", type of toasting/charring "*oak treatment*", the combination of maturation vessel size and oak type "*vessel*", and an interaction affect between "*vessel*" size/type and "*oak treatment*" to capture the variation derived from differing oak sources and cooperage methods. Pairwise comparison of factor means was undertaken using Fisher (LSD) at $\alpha = 0.05$.

RESULTS AND DISCUSSION

1. Evaporation

LSBAs showed evaporation rates of 5–10 % per annum (Figure 5), higher than the approximately 5 % evaporation per annum observed for conventional 200–220-L barrel maturation in a temperate climate (Jeffery & Berglund, 2016), while lower than the 10–12 % evaporation observed for the 28-L casks (Figure 5). The lower evaporation experienced by the LSBAs compared to small format (*e.g.*, 28-L) casks is a positive finding for experimental studies that require longer duration, and within a proximate range of evaporation rates for commercial casks stored in warmer or drier climates. However, the gap between this figure and the lower bound of evaporation experienced in commercial 200-L+ casks indicates that there is still some room for further optimisation of the design. The ANOVA showed that only variation in vessel size was found to be significant (*vessel* $p < 0.0001$) in predicting evaporative losses, with other factors not found to be significantly different (*variety* $p = 0.693$, *oak treatment* $p = 0.412$ and *vessel* × *oak treatment* $p = 0.612$).

It is worth noting that a GLS 80 bottle holds more than 1 L when brimful, so even at filling there is some headspace above the liquid when stored horizontally. Importantly, the oak discs were fully wetted both at filling, where the level was above the shoulder of the container, and at emptying where the level had fallen below the shoulder of the vessel. Despite this drop in fill level, the oak discs remained fully wetted through capillary action.

2. Maturation performance

This experiment was designed principally to verify the structural and functional efficacy of prototype LSBAs, so volatiles analysis was not a priority. This combined with the discrepancy in oak type and origin (American vs French oak wood), between the two vessel types (28-L FO Cask *vs* 1-L AO LSBA) meant that a comparison of volatiles would be of limited relevance and so was not conducted on the prototype LSBAs.

According to ANOVA, there was a significant difference in colour among the samples according to the fixed factors, with the combined model significant ($p < 0.0001$ and $F = 143.019$). The variance in least square (LS) means for each factor was also significant with *variety*, $p < 0.015$; *vessel*, $p < 0.0001$; *oak treatment*, $p < 0.015$ and *vessel* × *oak treatment* $p < 0.002$. A summary table of the LS means and pairwise comparisons for the variables is included in Table 1 below. The statistical significance of the colour measurement between the different maturation vessels was expected, especially given their vastly different rates of surface area to volume and variation in oak sources. However, the statistical significance of the variation in colour between the different varietal sprits was an interesting result. It is challenging to propose a sound reason for this outcome, although there is some suggestion in the early literature that a lower pH will increase oak phenolic extraction (Puech, 1987). The pH for the un-matured spirits was 5.67 for the Sauvignon blanc, 5.57 for the Shiraz (Syrah) and 5.37 for the Pinot noir. The similar trend between the pH of the varietal spirits and the colour of their barrel replicates suggests that may be at least a contributing factor.

The very low extraction shown in the colour values of the LSBAs when compared to the 28-L ($\frac{S}{V}$ ~17.5 m^{-1} (Del Toro Del Toro *et al.*, 2023) casks is most likely due to the surface area to volume ratio of these vessels being lower than even commercial casks. A 220-L barrique has a surface area/volume ratio of ~8.8 m^{-1}, (Del Toro Del Toro *et al.*, 2023) whereas based on a volume of 1-L and a disc diameter of 77 mm, the model vessels have an estimated surface area/volume ratio of ~4.65 m^{-1}. This value is closer to the estimated value for a 500–600-L cask (puncheon/sherry butt), which is amongst the largest barrel sizes used in commercial distilleries (Conde-Fernández *et al.*, 2020). The ~4-fold difference in surface area to volume between this and the 28-L casks, combined with differences in toasting procedures, could explain the ~7-fold difference in LS means observed from absorbance data. While this low level of extraction in the LSBAs is an improvement over the use of small-format casks, it could be further modified in future versions of the model vessel by part filling the LSBAs and storing them inverted to keep the oak discs in full contact with the liquid. Alternatively, it may be possible to use 250 ($\frac{S}{V}$ ~18.6 m^{-1}) or 500 mL ($\frac{S}{V}$ ~9.3 m^{-1}) versions of the GLS 80 bottle in the LSBAs, which would be closer to the surface area to volume of a 28-L cask and 220-L barrique respectively, the latter being more commonly used in industry. The drawback of using LSBAs with smaller fill volumes or GLS 80 bottles of less than 1 L is the decrease in the amount of matured spirit available for sensory analysis. The initial size trialled here (1-L) was chosen as the minimum size necessary to have approximately 60 × 30 mL (at 20 % ABV) servings available for rate-all-that-apply sensory analysis upon completion of the maturation trial (Danner *et al.*, 2018).

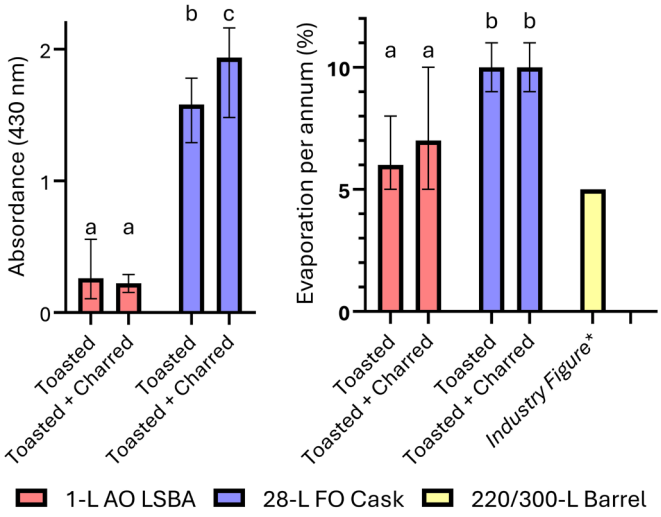


FIGURE 5. Comparison of colour (430 nm) and evaporation rate for all varieties after two years of maturation in different vessel types, with α = 0.05 pairwise comparison using Fisher LSD.

AO, American Oak; FO, French Oak; LSBA, Lab-scale-barrel-analogue, *(Jeffery & Berglund, 2016).

TABLE 1. Predicted Least Square means from ANOVA of absorbance at 430 nm.

Factor	LS mean	Standard error	Pairwise comparison (Fisher LSD)
Variety:			
Sauvignon blanc	0.911	0.049	A
Shiraz	0.968	0.049	A
Pinot noir	1.134	0.052	B
Vessel:			
28-L FO Cask	1.758	0.042	A
1-L AO LSBA	0.251	0.039	B
Oak Treatment:			
Toasted	0.927	0.041	A
Toasted + Charred	1.081	0.041	B
Cask Size/Type × Oak Treatment:			
28-L × Toasted (*"Alcohol + Toast"*)	1.580	0.060	A
28-L × Toasted + Charred (*"Vanilla Toast"*)	1.935	0.060	B
1-L LSBA × Toasted	0.275	0.056	C
1-L LSBA × Toasted + Charred	0.227	0.056	C

AO, American Oak; FO, French Oak; LSBA, Lab-scale-barrel-analogue.

3. Prototyping, integrity, and viability of the LSBAs as experimental vessels

Initial prototyping iterated through many designs before settling on the design included here. The first designs were based on the more common GL 45 thread bottles but were replaced with the larger GLS 80 thread bottles to ensure, at an appropriate surface area to volume ratio, that the working volume would be adequate for chemical analyses and sensory studies. Several adjustments to the design were also found to improve the method during prototyping such as removing the pouring lip from the bottles to improve sealing performance against the silicone gasket, and the addition of a hex nut to the external finish of the cap (and matching spanner) as hand tightening was found to apply insufficient torque to the caps to facilitate a good seal. Filament options were evaluated from a range of supplier material guides and research literature (Heikkinen *et al.*, 2018) and ABS was selected for this trial due to a combination of chemical resistance and strength.

After maturation for two years there was found to be a failure rate of 22 % for the additive manufactured caps, with 4 of the 18 vessels leaking (two toasted, two toasted and charred, two Pinot noir, one Shiraz, one Sauvignon blanc) the majority of their contents. Of those caps that failed, most failed around one year into the trial. This failure appears to be the result of fine leaks that have led to material fatigue and a cascade failure in the print leading to accelerated weakening and eventual structural failure. An example of one of these failures is included in the supplementary materials (Figure S1). While the LSBAs were checked monthly, due to the accelerating failure of caps once weakened from an initial leak, there was limited opportunity to catch failing caps and swap them out before a total loss of an LSBAs contents. Data from the failed LSBAs were therefore not considered further.

While ABS was initially identified as a promising option for the caps, given the failure of a percentage of the caps due to print layer delamination, there is room for further improvement in the additive manufacturing aspect of these research vessels. The occurence of significant mechanical stress in this design, in addition to the complex composition of brandy distillates as a solvent may mean a higher mechanical and chemical resistance is required for an optimised design. The choice of filament, print infill and even print methodology (FDM *vs* SLA) may all need to be further refined to avoid the proportion of failures experienced in the present work. Depending on the material used, printing the caps at a higher infill (*e.g.*, 100 %), adjusting layer orientation to improve dimensional strength, and trialling newer resin type prints (SLA) may improve the resilience of caps and eliminate failures over longer maturation time frames.

Refinement of the stainless-steel hot plate cover could improve the replicability of the toasting process. Based on visual observation while toasting, the laboratory hot plate showed a hot spot in the centre leading to uneven heating and toasting of the discs. A thick copper sheet placed between the hot plate and the stainless cover may more evenly spread the heating interface, improving the evenness of the toast. While toasting, temperatures on the oak discs were verified by an IR thermometer and showed that thermocouple placement, on the edge lip of the cover, consistently read under the interface temperature. Moving it to a central location on the hotplate surface may give a more accurate reading. There is significant variation in the literature about the combination of toasting time and temperature to achieve a "medium toast", but based on a number of sources (Bautista-Ortín *et al.*, 2008; Chatonnet *et al.*, 1999; Collins *et al.*, 2015; Hale *et al.*, 1999;

Tamayo-Sánchez *et al.*, 2023), the combination selected in this work was an appropriate compromise.

While the toasting process employed in this study showed room for improvement the method employed for charring the LSBA discs was comparatively consistent and replicable. The colour measurement at 430 nm (Figure 5) showed that the toasted and charred discs were more consistent (coefficient of variation (CV) 22 %) in their extractive potential than the discs that were simply toasted (CV 70 %), with absorbance as low as 0.106 and as high as 0.557. The LSBA caps also failed an equivalent amount (22 %) for both oak treatments, suggesting that the charring process did not negatively impact the integrity of the sealing interfaces. Nevertheless, further work is warranted to verify the accuracy and replicability of the toasting and charring methods used here to achieve a level of toast and char similar to that of commercial casks, ideally through quantitative comparison of oak extractive volatiles and maturation by-products.

4. Conclusions

The proposed design (LSBA) for a cost-effective solution to simulate the barrel maturation process in a laboratory shows significant promise from a functional and cost perspective. LSBAs demonstrated improved evaporation control versus small format (28-L) barrels, a lower requirement for spirit volume and storage space for maturation replicates, and decreased costs compared to other published methods for pilot barrels. The final cost per unit of these vessels (without oak) amounted to approximately 48.15 $AUD, comprising a 1-L GLS 80 bottle 27.50 $AUD, two silicone gaskets at 8.30 $AUD each and 110 g of ABS filament per cap at 4.05 $AUD. Oak costs were not included in this comparison because the alternatives proposed by Snakkers *et al.* (2003) would use a roughly equivalent amount of oak, and costs may vary widely depending on oak origin, treatment, seasoning, and age of the sample of interest. This figure is close to 10 % of the cost of the stainless-steel vessels mentioned in the literature (Snakkers *et al.*, 2003) and would therefore be amenable for experiments that require barrel maturation and considerable replication. With further developments and the increasing ubiquity of AM processes, it is anticipated that the cost of the caps will decrease with time. Future improvements to the LSBA design have been proposed based on the printing methodology of the caps (material choice and print settings to avoid failure), oak treatment (improving the accuracy of toasting) and vessel size (to alter $\frac{S}{V}$ ratio and extraction rate), which collectively could more closely replicate a commercial barrel of a requisite size.

Ultimately, the prototyping undertaken in this study offers a promising small-scale spirit maturation format. By sharing this preliminary concept and the associated design files, further improvement is encouraged, such that a standardised method based on model vessels may be developed for adoption in spirit maturation experiments involving brandy, whisky, rum, etc. With further work to verify inter-laboratory replicability this may facilitate an improvement in the comparability of results between maturation experiments across institutions and improve replicability within experiments.

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CREDIT AUTHOR CONTRIBUTION STATEMENT

Hugh R. Holds: Conceptualisation, Formal Analysis, Funding Acquisition, Investigation, Methodology, Validation, Visualisation, Writing – Original Draft Preparation, Writing – Review & Editing. **Kerry L. Wilkinson**: Conceptualisation, Resources, Supervision, Writing – Review & Editing. **David W. Jeffery**: Conceptualisation, Resources, Supervision, Writing – Review & Editing. **Frances Jack**: Conceptualisation, Resources, Supervision, Writing – Review & Editing. **Susan E. P. Bastian**: Conceptualisation, Project Administration, Resources, Supervision, Writing – Review & Editing.

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