Journal of Animal and Feed Sciences, 35, , 2026, e27, https://doi.org/10.22358/jafs/214458/2026
The Kielanowski Institute of Animal Physiology and Nutrition, Polish Academy of Sciences, Jabłonna

ARTICLE IN PRESS

ORIGINAL PAPER

Effect of spent brewer's yeast (*Saccharomyces cerevisiae*) inclusion on the physical characteristics, water activity, and stability of fish feed

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KEY WORDS: aquaculture, aquafeed, extrusion, isotherm, spent brewers' yeast

Received: 12 September 2025
Revised: 19 November 2025
Accepted: 19 November 2025

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ABSTRACT. Spent yeast from brewing fermentations is a potential alternative protein source to fishmeal in aquafeed formulations. Using an easily replenished waste stream as a protein replacement would assist with sustainable aquaculture production. Therefore, the primary goal of this study was to assess physical properties of a fishmeal-based aquafeed containing spent brewer's yeast as a partial protein substitute. This was performed by comparing three pelletized feed formulations containing no yeast, live yeast, and a thermally lysed (dead) yeast. Four primary physical characteristics of the feeds were tested including macronutrient content, texture, water activity, and water stability. For assessment of physical parameters, pellets were dried to ~15% moisture content on a wet basis (MCwb) and ~5% MCwb. Moisture sorption isotherms were practically identical across all three feed formulations, indicating that significant modification of preparatory practices when extruding yeast-modified fish feeds is not needed. Maximum hardness was positively correlated with moisture content and with yeast inclusion. The water stability was lower at lower moisture contents over the course of the first two hours of sampling, but was not correlated after four hours, and decreased with yeast inclusion. Water stability was the lowest for live-yeast inclusive feeds, in which almost all (~90%) solids were lost after 240 min of water exposure. This study examined several key physical effects which incorporating living or dead yeast into an extruded fish feed would be expected to cause, thus forwarding their development as a sustainable protein alternative.

Introduction

Modern aquaculture relies heavily on fed aquaculture, in which fish are fed formulated feed often containing fishmeal as a primary protein source. As modern aquaculture continues to grow, fed aquaculture systems can cause negative effects on fish populations used for these systems (Tschirner and Kloas, 2017; Froehlich et al., 2018). One potential solution to alleviate the environmental impact created by current fed aquaculture methods is to supplement spent brewer's yeast (SBY) in formulated aquafeeds as an economical partial protein replacement (Covert et al., 2025). Breweries create large amounts of yeast as a waste stream in industrial fermentations that could provide a constant source of yeast to the

aquaculture industry (Huige, 2006). With 180 mln barrels of beer produced in the United States annually, 50–65 mln kg of spent yeast is generated (using the estimation provided by Huige (2006) it is of ~0.27–0.36 kg of spent yeast per 159 l (barrel) of beer). Most often, spent yeast is used as livestock feed (Jaeger et al., 2020). SBY is high in protein and contains an amino acid profile that is complete for fish growth (Jaeger et al., 2020; Covert et al., 2025), making it a candidate for application in fish feeds (FAO, WHO, UNU, 1985; Vieira et al., 2016). It also has well-documented benefits for fish when used as a partial protein replacement in aquafeeds. Live yeast inclusion in fish diets has resulted in increased growth performance in species such as Nile tilapia (*Oreochromis niloticus*) (Lee et al., 2025a), trout (*Oncorhynchus mykiss*), and freshwater catfish (*Mystus cavasius*) (Lara-Flores et al., 2003; Sheikhzadeh et al., 2012; Banu et al., 2020). Additionally, hop acids present in spent yeast slurries have been found to promote growth in young Nile tilapia (Lee et al., 2025b). However, unresolved growth affecting co-factors present in the yeast proteins, hop acids, and nucleic acid have produced mixed results from yeast inclusion (Lee et al., 2025a). Live yeast inclusion results in increased feed efficiency when fish are young and maturing (Gatesoupe, 2007) and has also been shown to result in increased phagocytic, respiratory burst, and myeloperoxidase activity (Siwicki et al., 1994). Conversely, the inclusion of dead yeast has not been shown to consistently impart positive immune effects (except for protection against *Aeromonas hydrophila*, which live yeast inclusion also imparts) but has been shown to sporadically increase growth performance in some species, such as tilapia (Ran et al., 2016). These benefits could be economically beneficial for aquaculture facilities. Additionally, SBY is a very cheap form of alternative protein (Jaeger et al., 2020), and could result in decreased feed costs for farms.

SBY is an underutilized by-product of the brewing industry (Jaeger et al., 2020). The most popular method of discarding yeast biomass is to sell it or give it away for utilization in animal feed after heat inactivation, as yeast is also considered a viable alternative protein source for ruminant feeds (Jaeger et al., 2020). Yeast biomass is also used in the food industry to produce yeast protein concentrates and isolates (Ferreira et al., 2010). However, although breweries create large amounts of spent yeast biomass, they rarely profit from its disposal (Serviss et al., 2025). In a study of English craft breweries, Kerby and Vriesekoop (2017) found that only 16.7% of large urban breweries profited from their SBY, while few small urban or rural breweries profited at all. Additionally, wastewater treatment and disposal often account for a large portion of brewery expenses, especially for small craft breweries (Brewers Association, 2017). Water with high biological oxygen demand (BOD) and total suspended solids (TSS) (both of which increase with spent yeast inclusion) accounts for about half of the costs associated with wastewater in many breweries (Brewers Association, 2017). Sourcing SBY to commercial aquaculture facilities could provide a new source of profit for breweries, and a low-cost protein alternative for the aquaculture industry, where feed costs make up nearly half of aquaculture facilities' expenses (Manitoba Agriculture Office, 2018).

Pelletized aquafeeds are usually produced by screw extrusion and are dried to a range of moisture content and water activity levels that are conducive to shelf-stability (Hilton et al., 1981; Sørensen, 2012). Typical commercial fish feeds are complete, meaning that they contain all necessary nutrients for fish health and growth (Covert et al., 2025). These fish feeds normally contain protein (18–50%); lipids (10–25%); ash (<8.5%); phosphorus (<1.5%); and water (<10%) (Craig et al., 2017). Complete diets are necessary when fish do not have the ability to find food themselves. Conversely, supplemental diets, which do not contain all necessary nutrients, are adequate when farmed fish can forage for their own food (Craig et al., 2017). Because protein supplies amino acids that promote organism growth, it is often the most prominent nutrient in fish feed. Other nutrients, most often carbohydrates, are removed to make room for increased protein content (Miles and Chapman, 2007). Reducing moisture content also increases nutrient density (Miles and Chapman, 2007). During feed extrusion, pressure, temperature, and shear force are used to gelatinize starches and potentially crosslink compounds within dough that can be shaped using a die (Sørensen et al., 2010). Typically, high moisture contents and low barrel residence time aid in nutrient conservation of feeds (Sørensen et al., 2002).

For the aquaculture industry to effectively utilize SBY in aquafeed formulations, information regarding the relationships between moisture content and water activity (a_w) of the feeds (moisture sorption isotherm) is required. Water activity values are necessary to determine shelf-stability and appropriate preservative requirements. While the authors have found little work on aquafeed specifically, values below 0.60 are considered completely stable for pet food components (Lowe and Kershaw, 1995). Feeds with >0.60 are not suitable for long-term shelf-storage unless stored under refrigerated

conditions, where the United States Food and Drug Administration (FDA) still recommends values of <0.85 (FDA, 1984). Models can be built through equations such as the GAB (Guggenheim-Anderson-de Boer) equation, which has been shown to accurately assess the sigmoidal relationship between the two variables in previous research (Lewicki, 2008). The GAB model is most effective at water activity values between 0.10–0.90 (Timmermann et al., 2001; Blahovec and Yanniotis, 2008), making it practical for use with aquafeed and in this study, as it allows identification of parameters such as the monolayer region, enabling producers to predict and optimize product stability.

Other important assays in the assessment of fish feed physical parameters are texture analysis and water stability. In texture analysis, maximum hardness is described by the peak force measurement during compression by a cylindrical probe (Hansen and Storebakken, 2007). However, hardness tests are not standardized across the literature, making direct comparisons between research difficult (Sørensen, 2012). Water stability (how the pellets retain cohesion in an aqueous environment) is important in aquafeed analysis because low water stability can result in increased nutrients and uneaten feed in farm effluent, as well as oil accumulation in fish stomachs (Baeverfjord et al., 2006; Mateo-Sagasta et al., 2017). As the relationship between water stability and submersion time is non-linear, a model such as the logistic model can be used to determine the relationship between water stability and time.

The aim of this study was to assess the physical properties of extruded fish feeds with 20% of the protein replaced with SBY (both live and dead) at various moisture levels. The macronutrient compositions, moisture sorption isotherms, texture, and water stability of the feeds were evaluated. This study was designed to provide insight for how spent brewer's yeast can best be used by the aquaculture industry through examination of how the physical properties are affected by yeast inclusion.

Material and methods

Aquafeed formulation

One test feed was produced with live yeast, while the other used yeast which was thermally lysed (henceforth referred to as dead yeast). Ale (*Saccharomyces cerevisiae*) yeast for yeast-inclusive feeds was harvested from completed fermentations from a local commercial brewery (First Magnitude Brewing Company, Gainesville, USA). Live yeast was kept refrigerated until ingredient mixing. The remainder of the yeast was autoclaved at 121 ˚C for 15 min to thermally lyse all cells. Both live and thermally inactivated yeast slurries were centrifuged at 275 for 6 min to create a concentrate more conducive to extrusion, as well as to eliminate residual beer from the solution. The control feed composition was modelled after commercially available sturgeon feeds (Sturgeon Food Pellets – Orchard Fisheries, Worthing, UK; sera Sterlet Pellets, Sera, Heinsberg, Germany), in which common ingredients present in researched commercial feeds were utilized. Feed macronutrient compositions, diameters (6 mm), and ingredient selection were based on a synthesis of multiple commercial sturgeon feeds, analysed for common ingredients. Ingredients found in most commercial sturgeon feeds were whole and all-purpose flour, fishmeal, and fish oil. Using these ingredients, feeds that incorporated live and dead yeast to replace 20% of the protein (otherwise supplied by fishmeal) were formulated. For the yeast-inclusive feeds, yeast protein replaced 20% of the protein usually derived from fishmeal in these feeds, and other ingredients were balanced as to keep the total macronutrient concentrations constant to the control feed. Table 1 displays the mass of each ingredient included in each batch of feed, while Table 2 displays the theoretical pre-extrusion macronutrient concentrations derived from calculation (not including added water for yeast-inclusive feeds). Ingredients were weighed and then mixed in a Hobart Legacy HL200 (Troy, OH, USA) ~19 l (20 qt.) mixer until homogenous. Batches of approximately 2.5 kg were produced for all three feeds.

Table 1. Masses of ingredients (kg) included in feed formulations

Feed formulation	Fishmeal	Whole wheat flour	All-purpose flour	Fish oil	Water	Live yeast slurry	Dead yeast slurry
Control feed	1.18	0.28	0.33	0.08	0.65	-	-
Dead yeast feed	0.94	0.23	0.23	0.08	0.18	-	0.76
Live yeast feed	0.96	0.24	0.21	0.07	0.02	1.03	-

Table 2. Macronutrient compositions of feed formulations

Feed formulation	Moisture	Protein	Fat	Carbohydrate	Ash
Control feed	33.4	31.0	8.1	16.9	10.6
Dead yeast feed	34.5	30.6	8.1	17.3	9.5
Live yeast feed	34.5	30.7	7.8	17.4	9.6

composition of raw ingredients is based upon calculation (%)

Aquafeed extrusion

Feeds were produced in approximately 2.5 kg batches, and were extruded in a single-screw pilot-scale extruder outfitted with a custom pelletizing die to allow consistent feed formulation. The extruder generated control pellets comparable to commercially available feeds using parameters within the limits described by Sørensen (2012). Feeds were extruded using a Demaco (Melbourne, FL, USA) single-screw extruder, rotating at 30 rpm at 60 °C. Dough mixtures were fed into the extruder at a rate of approximately 200 g/min. Pre-extrusion moisture contents of the control feed and thermally inactivated yeast-inclusive feed was 31% moisture content on a wet basis (MCwb), while the pre-extrusion moisture content of the live-yeast inclusive feed was 36% MCwb. These moisture contents were the minimal that allowed dough movement through the barrel resulting in consistent texture of final feeds. After extrusion the 6 mm diameter pellets were manually cut to a length of 15 mm.

Compositional analysis

After extrusion, the composition of the feeds was verified using external analysis. Compositional analysis of each feed was performed by Pacific Coast Analytical Services (San Fernando, CA, USA) using published methods of the Association of Official Analytical Chemists (AOAC International, 2012). Ash analysis was performed according to AOAC method 923.03. Crude fat analysis was performed according to AOAC method 920.39. Moisture analysis was performed according to AOAC method 984.25. Crude protein analysis was performed according to AOAC method 992.15. Carbohydrate composition was determined by subtraction.

Moisture sorption isotherm generation

Moisture sorption isotherms were generated for all three feeds to determine differences in the relationship between moisture content and water activity, and to determine potential long-term shelf stability. The three feeds were dried on perforated baking sheets at 60 °C in a drying oven and removed at timed intervals. A moisture sorption isotherm was generated by measuring water activity and moisture content (wet basis) from samples dried for identical times and plotting them against each other. Water activity was measured using a Meter Group (Pullman, WA, USA) AQUALAB 4TE water activity meter. Moisture content was measured by drying samples previously dried (60 °C) at 105 °C in a drying oven until constant weight was achieved.

Texture analysis

Texture analysis was performed to determine the force at rupture and the impulse of the feeds, as well as those values' relationship with individual pellet volume. Analysis was performed using a compression test with a Texture Technologies TA.XT Plus Connect (Hamilton, MA, USA) texture analyser outfitted with 35 mm cylinder probe. The probe descended until 3 mm of recorded compression was achieved. Analysis was performed on 30 pellets from each feed. Samples were chosen between feeds by attempting to match moisture contents for directly comparable analysis. Each pellet was individually measured by hand-held calliper (as pellet breaking force characteristics are often correlated to the pellet diameter). Maximum breaking force (N), impulse (N·s), maximum breaking force per unit volume ($N \cdot mm^{-1}$), and impulse per unit volume ($N \cdot s \cdot mm^{-1}$) were quantified. Impulse was calculated by summing the forces of each individual data point taken during each texture analysis run.

Water stability

Water stability was assessed the retention of solids after submersion in water for various times, a modified version of a method described by Baeverfjord et al. (2006) was used to determine water stability. Feed samples of 5 g were placed into wire baskets with 3 mm mesh size. The baskets were weighed before and after introduction of the sample. Baskets were placed into 600 ml beakers filled with 300 m of deionized water such that the pellets were submerged and incubated in an air shaker at 27 °C for 30, 60, 120, and 240 min while shaken at 100 rpm. After incubating, the mesh baskets were dried with tissue paper and placed into a drying oven at 105 °C until constant weight was achieved. The baskets were then weighed after this drying period. Water stability (WS) was calculated as proportion of solids (0–1) remaining after submersion in water over time as shown in equation:

$$WS = 1 - \frac{(M_{(i)} - M_{(f)})}{M_{(i)}},$$

where: M(i) – initial dry matter, M(f) – final dry matter. Analyses were performed in triplicate.

Statistical analysis

Statistical analyses were performed to analyse the differences between the moisture sorption isotherms, the textural characteristics, and water stabilities of the feeds.

Moisture sorption isotherm generation

Moisture sorption isotherms were generated in Prism (GraphPad, San Diego, CA, USA) using a three-parameter non-linear GAB model:

$$MCwb = \frac{c_g \cdot K \cdot M \cdot a_w}{(1 - K \cdot a_w) \cdot (1 - K \cdot a_w + c_g \cdot K \cdot a_w)},$$

where: c_g and K – constants specific to the food composition, a_w – water activity, and M – monolayer moisture content. The GAB model assumes isothermal conditions (Quirijns et al., 2005) when used to generate isotherms. All isotherms within this study were generated at 25 °C.

Texture analysis

One-way ANOVA followed by Tukey's HSD test was performed in RStudio (version 3.0.1, Boston, MA, USA) for all feed parameters analysed. Statistical significance was determined at $\alpha = 0.05$. Least significant difference (LSD) test was used to denote significant differences between samples in texture analysis and water stability results.

Water stability

Water stability curves were generated in Prism using a four-parameter logistic model. This equation is often used to model fermentation kinetics as shown in (Nemenyi et al., 2024):

$$y = 1 + \frac{(u - l)}{(1 + e^{(-b(x-m))})}$$

where: l – maximum asymptote, u – minimum asymptote, b – slope and m – inflection point. An extra sum-of-squares F-test at $\alpha = 0.05$ was performed in Prism to determine statistical significance between curves.

Results and discussion

Macronutrient content

Aquafeeds were successfully produced at each formulation: control without yeast, dead with 20% protein replaced with thermally lysed yeast, and live with 20% protein replaced with viable yeast. The extruded pellets were then dried until approximately equivalent moisture contents of ~15% MCwb and ~5% MCwb were attained, and images are shown in Figure 1. The compositions of the feeds closely aligned with expected values derived from formulation calculations. The similarities in macronutrient profiles of all feeds allowed for direct comparison of analyses performed. The compositions of each feed as determined using AOAC methods (AOAC International, 2012) are detailed in Table 3.

Figure 1. Fish pellets derived from the three different preparation treatments

As per the recipe formulations, total protein, carbohydrate, and lipid remained nearly constant on a percentage basis between feeds of similar moisture contents (Table 3). At approximately 15% MCwb, all three feeds had an below 0.85 (as shown in Table 3) which is typically considered stable (FDA, 1984). However, products in this range (>0.6) are still susceptible to mould and yeast growth (Barbosa-Cánovas, 2007), necessitating the use of temperature control, preservatives, or quick use. Despite high moisture feeds having values above 0.60, no mould growth was observed after ~120 days of storage at refrigeration temperatures for any of the feeds.

Table 3. Macronutrient compositions (%) and water activity (a_w) of feeds

Pellet composition (at 15% MCwb[I])	Control	Dead	Live
Fat, %[II]	12.3 ± 0.3[A]	11.0 ± 0.8[A]	11.9 ± 0.7[A]
Protein, %[III]	36.8 ± 0.5[A]	35.4 ± 1.0[A]	38.0 ± 1.3[A]
Carbohydrate, %[IV]	22.1 ± 0.1[B]	26.5 ± 0.4[A]	21.5 ± 0.1[B]
Ash, %[V]	13.8 ± 0.2[A]	12.1 ± 0.7[A]	13.6 ± 0.6[A]
Water activity (a_w)	78.1 ± 0.6[A]	76.8 ± 1.6[A]	77.0 ± 0.4[A]

[I] – AOAC method 984.25; [II] – AOAC method 920.39; [III] – AOAC method 992.15; [IV] – subtraction; [V] – AOAC method 923.03. Values reported as mean ± standard deviation, n = 2 for composition and 3 for water activity; [AB] – means within a row with different superscripts are significantly different at $P < 0.05$

Texture

For texture analysis, 30 pellets of each feed composition and moisture content were compressed, generating approximately 2E+06 individual time-force measurements. The average maximum force to crush pellets of each feed is shown in Figure 2. A larger variance was observed in the tested parameters in the live yeast-inclusive feeds, which may have been due to some textural inconsistency of the feeds. Hardness and impulse were analysed individually and in conjunction with diameter of pellets, as pellet diameter has been connected to texture analysis characteristics in previous studies, in that smaller diameter pellets often have lower hardness (Thomas and van der Poel, 1996). Maximum hardness and moisture content were positively correlated, meaning that at high moisture contents hardness

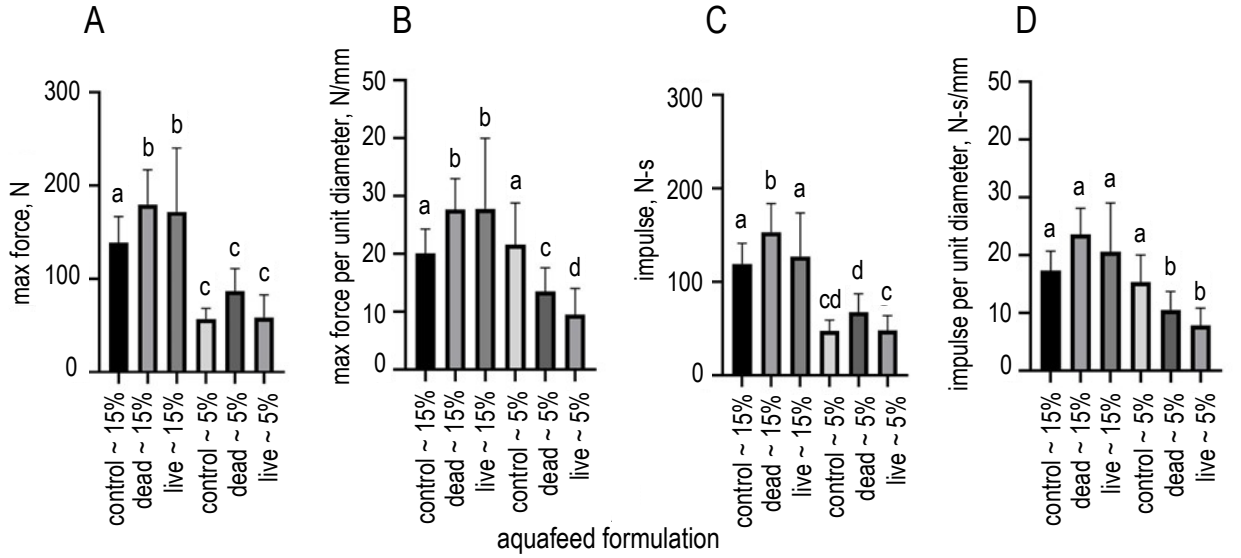

Figure 2. Hardness (a), hardness per unit diameter (b), impulse (c), and impulse per unit diameter (d) of control, dead yeast-inclusive, and live yeast-inclusive feeds at ~15% MCwb and ~5% MCwb

n = 30; error bars represent standard deviations; a-d – bars with different superscripts are significantly different at $P < 0.05$

and impulse generally increased (Figure 2). At high moisture content (~15% MCwb), the inclusion of yeast often resulted in significant increases in force characteristics, especially for hardness and hardness per unit diameter. For impulse at ~15% MCwb, dead yeast inclusion resulted in significantly higher values than live yeast inclusion or no yeast inclusion. In relation to unit diameter, impulse increased upon yeast inclusion but not significantly. Overall, this data indicates that at high moisture, yeast inclusion results in matrix strengthening. At low moisture (~5% MCwb), the dead yeast-inclusive feed had larger force characteristic values than the live yeast-inclusive feed for all measurements but had significantly lower hardness per unit diameter and impulse per unit diameter than the control feed. Additionally, in relation to pellet diameter, the hardness and impulse of the control feed were not significantly different from high to low moisture, in contrast to the yeast-inclusive feeds, which had significant differences for these values from high to low moisture. This indicates that changes in moisture content had a much greater effect on the yeast-inclusive feeds than the control feed. According to Sørensen (2012), it is difficult to directly compare hardness data between studies due to methodological differences. However, the hardness values observed in this study align with previously reported values for aquafeeds, with Sørensen (2012) reporting hardness values in the 40–140 N range. These values are close to the values reported in this study, in which hardness values were between 50–180 N.

The force-time curve for the pellets within the texture analyser describes the breaking mechanism for the pellets. Figures 3 and 4 display force-time curves for feeds at ~15% MCwb and ~5% MCwb.

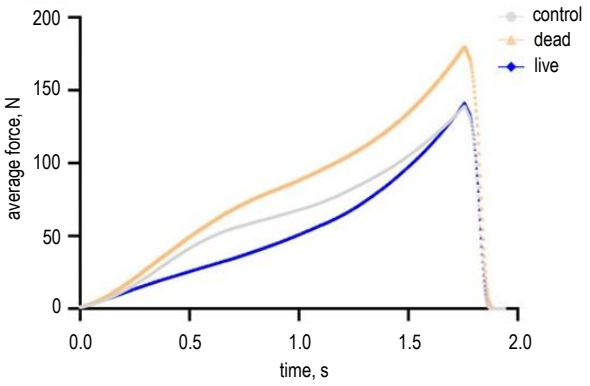

Figure 3. Overlaid force-time curves for control and yeast-inclusive feeds at ~15% MCwb

n = 30; standard deviations are not shown for clarity

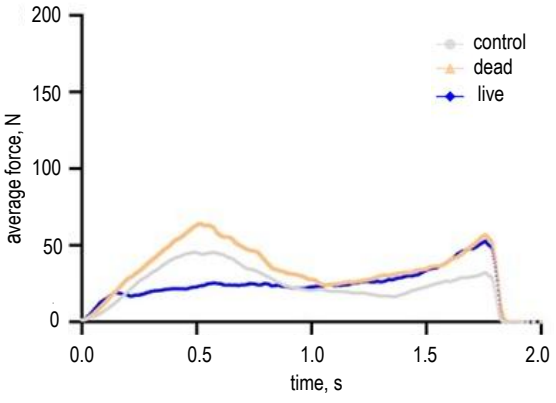

Figure 4. Overlaid force-time curves for control and yeast-inclusive feeds at ~5% MCwb

n = 30; standard deviations are not shown for clarity

The hardness of high moisture content feeds displayed a consistent slope followed by a sharp peak, while feeds at low moisture contents resulted in less consistent slopes, and in some cases multiple peaks (Figure 4) due to the brittle texture of the low moisture feeds. Standard deviations of each individual datum were also larger and less consistent over the force-time curve at lower moisture contents, possibly due to their more brittle texture, which often lead the feed pellets to shatter rather than flatten when compressed by the probe. Over-drying can result in lower hardness and durability, due to reduced adhesion strength of the liquid bridge (Sørensen et al., 2010), which likely contributed to the feed pellets shattering rather than flattening and caused decreased hardness.

Moisture/water activity

The drying process took 5 h in the drying oven, after which the moisture contents of samples did not measurably change. Samples were assessed for MCwb and every 30 min from 0–4 h, and every hour from 5–12 h. The moisture sorption isotherms of the control feed and yeast-inclusive feeds were practically identical, as displayed in Figure 5. This result indicates that inclusion of yeast in feed formulations does not affect the drying relationship with moisture content. The monolayer for all feeds was ~4% MCwb (= 0.25), below which feeds will become unstable and prone to oxidation (Salwin, 1959). These results are independent of initial moisture content. While dead yeast-inclusive feeds could be extruded at the same initial moisture content as yeast-free formulations (31% MCwb), live yeast started at higher MCwb (36% MCwb) to be successfully extruded. Drying time to reach final moisture contents varied slightly across feeds, with the control feed taking about 2 h. to reach 15% MCwb and the yeast-inclusive feeds taking about 2.5–3 h. to reach the same moisture content. Just as in extrusion, these differences between control and yeast-inclusive feeds do not necessitate significant procedural modifications in the preparation of yeast-modified feeds.

Differences between the control feed and the dead yeast-inclusive feed may be explained by the degradation of the cell membrane caused by thermal stress, a phenomenon observed by Adya et al. (2006), among others. For slow-eating species, it may be necessary to modify feeding regimes to minimize feed waste integration into the system.

Water stability

Water stability is an indicator of how long the feed will remain viable within an aquaculture system and is necessary to determine for which fish species the feed is suitable. Figures 6 and 7 display the water stability curves of feeds at ~15% MCwb and ~5% MCwb, after agitation at 100 rpm (at 27 °C). Statistical significance ($P < 0.05$) was observed for all three curves at both ~15% MCwb and ~5% MCwb, showing that the inclusion of yeast sig
Figure 7. Water stability index at ~5% MCwb n = 3 for each feed sample; calculated using proportion of solids remaining over time with 4P logistical model fit, bars showing standard deviation (α = 0.05) inificantly changes the water stability of feeds. The control feed was significantly more stable than the yeast-inclusive feeds, while the dead yeast-inclusive feed was significantly more stable than the live yeast-inclusive feed. The water stability decreased over submersion time for all three feeds at both moisture contents. At ~5% MCwb, the rate of dry matter

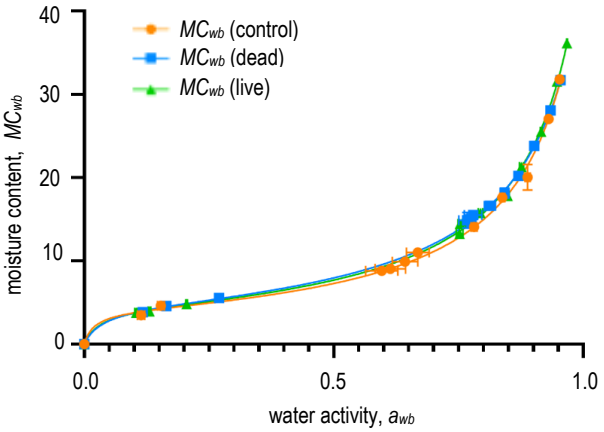

Figure 5. Moisture sorption isotherm of control and yeast-inclusive feeds
The GAB model was fit for all datasets (using Equation 1) and is represented via solid lines; n = 3; standard deviations represented by vertical and horizontal error bars

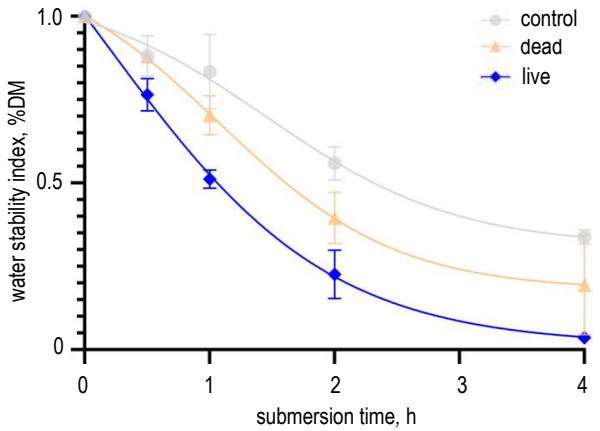

Figure 6. Water stability index at ~15% MCwb
n = 3 for each feed sample; calculated using proportion of solids remaining over time with 4P logistical model fit, bars showing standard deviation

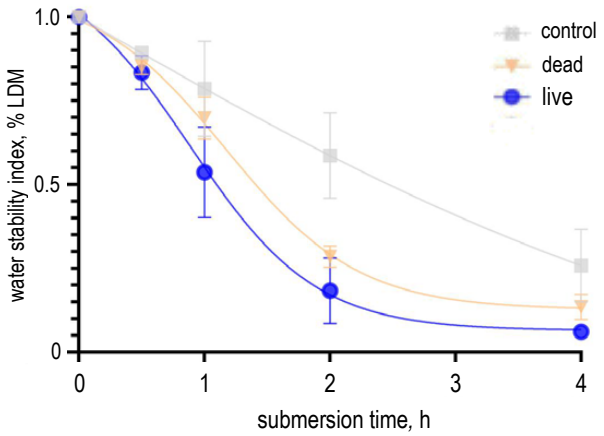

Figure 7. Water stability index at ~5% MCwb

n = 3 for each feed sample; calculated using proportion of solids remaining over time with 4P logistical model fit, bars showing standard deviation; %LDM – loss of dry matter

loss was greater over the first 2 h of sampling than at ~15% MCwb. Both yeast-inclusive feeds experienced near complete dry matter loss after 4 h of water submersion. The high rate of dry matter loss over extended submersion times will potentially affect feeding regimes for slow-eating aquaculture species, as increased integration of fish feed dry matter waste into the system may negatively affect water quality and other parameters (Pedersen et al., 2012).

Conclusions

This work examined key parameters of aquafeeds with live and dead yeast inclusions. The macronutrient contents of the three feeds were found to be closely aligned with the expected values from initial calculations suggesting that any differences in the other measured parameters were likely derived from structural differences, rather than compositional differences of the feeds. The maximum breaking force of the feed pellets increased for pellets with yeast inclusion and with higher moisture content. The control feed at ~15% MCwb had a hardness per unit diameter of ~20 N/mm, compared to ~27 N/mm for both yeast feeds. At ~5% MCwb, however, the hardness per unit diameter of the control feed did not change significantly, whereas that of the yeast including feeds dropped substantially (~13 N/mm for the dead yeast feed and ~9 N/mm for the live yeast feed). A similar trend was observed in the impulse per unit diameter measurements. If considered for industrial application, the hardness of feeds would need to be considered carefully for target fish species, complicated by the hardness shifting significantly with moisture content. The moisture sorption isotherms of all feed formulations were practically identical, despite significant differences in all other assessed parameters. This is important when considering the formulation and production of yeast-inclusive feeds, as preparation of yeast-inclusive feeds will not require significant departures with respect to water activity or storage conditions. The water stability was highest in the control feed, followed by the dead yeast-inclusive feed, and the live yeast-inclusive feed, respectively. It is believed that the addition of yeast in the feeds caused lower solids retention, especially in the live yeast-inclusive feed, due to matrix differences in the finished feeds. The water stability of the live yeast feed was concerning, showing ~%50 loss after an hour of submerged agitation. Mitigation strategies for negative effects on aquafeed quality due to yeast integration could include the addition of binders or other gelling agents to increase the hardness and water stability of yeast-inclusive feeds.

The findings of this study suggest that aquafeeds containing spent yeast will have significant textural and stability differences from that of standard formulations. The inclusion of brewer's yeast into aquafeed presents a new direction for craft brewing waste streams. By sourcing spent yeast that cannot be used in fermentations to aquaculture facilities, breweries can offset many of the costs associated with wastewater disposal, while also providing aquaculture facilities a reliably supplied and sustainable protein source. However, to fully take advantage of these benefits, both the brewing and aquaculture industries must be aware of the challenges associated with incorporating large amounts of yeast into traditional recipes as assessed in this study.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Acknowledgements

The authors would like to acknowledge First Magnitude Brewing Company for their many donations of SBY, and technical support throughout the project. We would also like to acknowledge student support provided by the Lee C. Yeoman's Fisheries and Aquatic Sciences Fellowship Fund, as well as by the Department of Food Science and Human Nutrition of the University of Florida.

Conflict of interest

The Authors declare that there is no conflict of interest.

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