Evaluation of Filter Cake Oil as Antifoam in Yeast Production: New Use for this By-Product of the Sugarcane Derivatives Industry

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Received: 30 March 2021 / Accepted: 10 September 2021 / Published online: 24 September 2021
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Abstract
Purpose Fodder yeast is obtained in an aerobic fermentation process where foaming is a major problem to be solved. In this article, the antifoam property of crude and purified filter cake oil is evaluated in order to use this residual as an alternative to replace the import of commercial antifoam agents and to reduce the production costs of fodder yeast.

Method Knock down test and the comparisons with two commercial antifoam agents were done. Blackstrap molasses medium at 20 and 40 g/L of total reducing sugar was used. All products were studied in their pure form and commercial ones also in dilutions 1:2 and 1:5 v/v. Hansen's solubility parameters (HSPs) to analyze the affinity of each defoamer for yeast were determined.

Results It was obtained the crude and purified filter cake oil showed similar behavior to commercial defoamers with an immediate antifoam effect, removing between 40 and 60% of the initial foam at both sugar concentrations in the first 5 min. The regression model for both medium concentration showed purified filter cake oil has the greatest knockdown effect (Ca = 57.00 and 74.11) and with greater foam suppression stability the commercial defoamer Quimifoam Máster (Cb = − 1.05 and − 1.51) respectively. Ra values obtained in HSPs test, indicated the affinity of defoamers to the medium.

Conclusion Purified filter cake oil is an effective product for its use as an antifoam with the best knock down effect for both concentrations of sugars in the medium. The determination of HSPs corroborates the effectiveness of this product to suppress foam.

Graphic Abstract

Keywords Antifoam property · Defoamer · Filter cake oil · Candida yeast · Hansen solubility parameters

Statement of Novelty
The use of crude filter cake oil, residual from the Cuban sugarcane derivatives industry, as an antifoam was previously studied in the 90 s using it as a fatty vehicle in mixtures with esters, achieving good results. In the bibliography consulted by the authors, no recent articles are reported on its use after it has been purified. Therefore, the novelty of this work is the
evaluation of the antifoam property of purified filter cake oil, which offers the possibility of a new use of this by-product with the consequent impact on the reduction of fodder yeast production cost by the replacement of commercial defoamers, products that are imported and with high prices in the market.

Introduction

In fermentation processes, foam formation is inevitable and occurs as a consequence of the introduction of large masses of air into the process and the presence of colloidal substances or long-chain organic compounds (soluble proteins, alcohols, etc.) [1]. There are different ways to control and/or remove foam, such as the use of mechanical devices, removal of foaming agents from process units that prevent their formation, spreading water over it or breaking down by applying pressured flows over foam [2]. However, the most widely used method is applying antifoam agents of different natures.

Candida utilis fodder yeast, commonly named Torula yeast, is the most widely used microorganism in the production of unicellular protein as an established product with good acceptance in feed formulation for animal nutrition [3, 4]. It is obtained from heavy aerobic fermentation of a sugar-rich medium where foam formation occurs, which is a major problem that must be addressed.

Proteins and soluble amino acids resulting from yeast autolysis influence the foam formation and its stability [5]. Foam occurs when a liquid forms a film that surrounds a gas. In a surfactant solution, such as Candida Utilis propagation medium, where there is a concentration of protein and soluble amino acids, hydrophilic groups are regularly arranged on the liquid side of the film and hydrophobic groups on the air side; therefore, the forces on the foam surface are balanced, so that foam has a constant film thickness and becomes stable. This balance is broken by the use of an antifoaming agent.

A wide range of antifoam commercial products with dissimilar properties and compositions have been used, but most contain oils (silicone, mineral, fluorocarbons), solid particles (silica, calcium, plastic beds), or mixtures of the latter with amphiphilic particles and molecules (alcohols, fatty acids, fatty esters) [6]. The defoamers used in yeast production are mainly based on fatty acids, fatty acid esters and aliphatic alcohols, among others [7].

Defoamer decreased the surface tension of aqueous system when the presence of a surfactant stabilizes the foam formation. Pure water has a surface tension of 72.8 dyn/cm at 20 °C, while vegetable oils have a surface tension between 31–39 dyn/cm at 20 °C [8] and between 31–21 at 23–200 °C [9], so some types of vegetable oils such as jojoba, sunflower, coconut oil, soybeans and rapeseed, have been reported as defoamers in different productions to replace commercial ones with good results [7, 10–12].

The mechanism of action of the different antifoaming agents has been described in deep in literature, included oil droplets ways of action. Oil drops destroy foams by various mechanisms: bridging–stretching, bridging–dewetting, and several mechanisms related to oil spreading [6]. Although a mechanism discussion is beyond of this work, it is important to remark that for any of the bridging mechanisms, the oil drop first connects the two film surfaces, that is, makes a “bridge” between them. Because that, the ability of antifoaming agent may be related with the affinity between this agent and the surfactant. This affinity could be correlated with the Hansen Solubility Parameters (HPS) of both compounds, as was showed in previous study by Kato et al. [13]. In their work, they confirmed a relationship between affinity of the antifoaming agents for the surfactant based on HSP theory and the defoaming effect.

Three years ago, a novel semi-empirical method for adjusting the total or Hildebrand solubility parameter to surface tension (σ) based on the use of Stefan’s rule, has been developed [14]. The semi-empirical model obtained by lineal regression of literature data is supported by the fact that both equations Stefan’s rule and Hildebrand solubility parameter (δT) establishes a dependence of σ and δT respectively with the enthalpy of vaporization (ΔHvap) and molar volume of the substances. Recently a paper of Nunes et al. [15] propose and innovative method for adjusting the three-dimensional HSP to surface tension. Through this, it is possible to obtain the HSP components that can be used to model applications that depend heavily on surface tension, such as defoamer selection.

Januskiewicz in an unpublished research and Montano et al. [16] studied filter cake oil for this purpose in fermentation industry, highlighting it has a composition, similar to some other (previous) vegetable oils reported by Cevada et al. [2], Kougias et al. [10], McClure et al. [12], Soomro and Sherazi [17], Chalupud et al. [18], Porto and Lopes [19], inducing a notable antifoam effect.

Filter cake oil composition, according to Montano et al. [16], Reinosa [20] and Silveira [21], is fundamentally constituted by a mixture of fatty acids such as linolenic (36.1%), palmitic (25%), oleic (10.2%), linoleic (6.9%), arachidic (7.6%), stearic (4.6%), myristic (3.1%), capric (1.2%) and caprylic (2.0%) and variable amounts of waxy esters (between 5 and 20%). These compounds have well-characterized defoaming properties according to the literature in this field [10, 12].

Filter cake oil is a by-product of sugarcane wax refining process. Its use as an antifoaming agent in fodder yeast production would be of interest to sugar and derivatives industry because it offers two options: the possibility of a new use of
this by-product and also it would have an impact on reduc-
tion of Torula yeast cost production by substituting com-
mercial defoamers, products that are imported and of high
prices.
In consulted bibliography by the authors, no recent
reports of the use of filter cake oil as antifoam were found.
In the reports of Montano et al. [16], antifoam effect of filter
cake oil as a fatty vehicle in mixtures with different esters
(monopalmitate, monomyristate, monostearate, monooeleate
and monostearate) was tested compared with sunflower
oil. In these studies, best results were obtained when filter
cake oil was used, with a similar procedure of commercial
defoamers. Taking these results as a starting point, the objec-
tive of this work is to evaluate antifoam property of pure
filter cake oil (without mixing with other compounds) in the
production of Candida utilis yeast.

Materials and Methods

Materials

Two types of filter cake oil, one with high content of wax or
crude (CACHA) (average dry base composition of 79% oil,
16% wax and 5% impurities) obtained from the sugarcane
wax refining factory annexed to Majibacoa sugar mill (Las
Tunas Province, Cuba) and other a purified filter cake oil
(CACHAP) were tested (processed) at the Cuban Research
Institute of Sugar Cane Derivatives (ICIDCA). Sugarcane
oil was purified according to the procedure described by
Hernández et al. [22], which extract the long chain ester,
aldehydes and fatty alcohols, remaining mainly lower
melting point compounds, such as some fatty acids. Also
two commercial defoamers: Silicone antifoam B30 (FV)
(non-ionic emulsion system) (Carini Chem SRL, Italy) and
Quimifoam Máster (C10) (anionic emulsion system) (Zucker
S.A, México), both specially used for fermentation processes
in alcohol distilleries and yeast plants, were evaluated.

Commercial defoamers were studied in their pure form
and in water dilutions of 1:2 v:v and 1:5 v:v, as this is the
way they are used in industry. In all cases, the behavior
obtained from them was compared with filter cake oils.

Methods

Defoaming Potential

To study the defoaming potential was made a Knock down
physical test; a 1000 mL cylinder with an air diffuser was
used. Air flow was provided by a compressor (Oks Otto
Klein Gmbh, Germany) and controlled by a flow meter. A
stopwatch (class 0.2 s) was used to measure time interval
in the experiments and a heating plate was employed to
increase the temperature of filter cake oil when applied to
the medium.

Defoamers were studied in the laboratory to know their
potential to suppress foam on a foamy medium made up of
molasses solution at 20 and 40 g/L of total reducing sugar
(TRS). These sugar concentrations was chosen because it is
a substrate being used in many fermentation processes, they
were likely to provide a foaming system broadly representa-
tive of industrial production of Torula yeast. As indicator
parameter of antifoam character was considered the effect it
produces over dynamic foam. Experiments were carried out
at room temperature (25 °C).

Procedure was done according to the method reported
by Montano et al. [16] and Kato et al. [13]. A 500 mL of
molasses solution was poured into the cylinder. Air flow
was adjusted at 4 vvm to promote foam formation of the
medium volume.

Molasses solutions at the concentrations used had differ-
ent fluid properties and material content (sugars and impuri-
ties), so the surface tension was not the same and this caused
the volume of the initial foam to be different.

When foam volume reached 600 mL for the solution of
20 g/L TRS and 650 mL for 40 g/L, a drop of the antifoam
to be evaluated (volume equivalent to 0.05 g) was dropped with
the aid of a micropipette. In the case of crude filter cake oil
was dropped 0.5 ml. After that, the volume of foam gener-
ated was measured every minute for a period of 15 min; this
way a “variable of response” was obtained, as “the relative
foam removal as a function of time”.

Relative foam removal (RFR) was calculated measuring
foam volume at minute 0 (without defoamer) as the initial
minute (ini) and at the other time intervals (t) as shown in
Eq. 1.

\[
\text{RFR} \% = \frac{\text{Foam volume (ini)} - \text{Foam volume (t)}}{\text{Foam volume (ini)}} \times 100 \tag{1}
\]

Regression Model

Taking into consideration what was proposed by Montano
et al. [16], as a second step of the knock down test, to deter-
mine the antifoam with the best knock down effect and the
highest stability of foam removal, a linear regression model
must be adjusted. Adjustment was made for pure defoamers
and at both concentrations of TRS in the medium. Antifoam
activity was characterized by the values of intercept (C_a)
and the slope (C_b) of the adjusted model.

In regression equation obtained (Eq. 2), intercept indi-
cates antifoam ability of rapidly depress of foam (knock-
down) while the slope is related to the duration or stability
of this effect. This way, best results are associated with the
highest values for C_a and C_b.
Relative foam removal = \( C_a + C_b \times \text{time} \)  

**Hansen Solubility Parameters Determination (HSPs)**

HSPs determination is a tool to express affinity degree between a solute and any solvent, based on the Hansen theory, which remarks “likes attracts likes”. Hansen parameters of different solutes and solvents (\( \delta_D, \delta_H, \delta_P \)) may be plotted in a three-dimensional graph plot x, y, z. Closer the solute–solvent pair is in a three-dimensional space, more soluble they are. Affinity of defoamers with surfactant medium (yeast) was determined quantitatively calculating the distance (\( R_a \)) of Hansen factors obtained for each one (Eq. 3).

\[
R_a = \left[ 4(\delta_H - \delta_D)^2 + (\delta_P - \delta_D)^2 + (\delta_P - \delta_H)^2 \right]^{1/2}
\]  

where \( \delta_D, \delta_P, \delta_H \): Hansen factors of coordinates d, p, h, 1: surfactant, 2: antifoam.

Good solvents for defoamer are inside a hypothetical sphere of radius \( R_0 \), called Hansen Sphere; so “good solvents” will get a relative energy difference (RED), defined as the ratio \( R_a / R_0 \), with values lower than 1.

\[
\text{RED} = \frac{R_a}{R_0}
\]

Hansen’s parameters were determined by Hansen solubility sphere method, from the affinity test with organic solvents of known HSPs. Hansen parameters of defoamers studied were obtained experimentally according to a methodology described in detail by Kato et al. [13] and Hernández et al. [22]. Through the Yamamoto Molecule Breaking (Y-MB) methods of contribution of functional groups and knowledge of their expression SMILE (Simplified Molecular Input Line Entry Specification), developed by Abbott and Yamamoto and available in HSPiP software version 5.2.0 [23]. Hansen parameters of *Candida utilis* yeast amino acids were determined because they were the soluble components of the medium causing the foam.

**Statistical Analysis**

In knock down tests each experimental condition was performed by triplicate and data were statistically analyzed in Statgraphics Centurion XVII.2 program, at time 5, 10 and 15 min.

One-way analysis of variance (Simple ANOVA) and the “least significant difference” (LSD) test was used to compare statistical differences between means values. Differences were considered significant at p value < 0.05. Also, to determine activity of each defoamer a regression model adjustment of relative foam removal as a function of time for the defoamers in pure form in each medium concentration studied was performed.

**Results and Discussion**

**Defoaming Potential**

Table 1 presents foam height values for all defoamers tested in this study during the 15 min time of the test and Fig. 1 shows the behavior of relative foam removal (RFR) versus time, obtained in knock down test. Four tested defoamers had an immediate effect over foam when they were added, decreasing its volume rapidly and keeping foam level controlled below the initial value throughout the test; this indicates the compounds are able in changing interfacial properties of a liquid, resulting in an extensive foam suppression.

In the first 5 min, it was possible to remove between 40 and 60% of the initial foam at both concentrations (20 and 40 g/L of TSR), although higher values were sometimes reached for the latter concentration. These results coincide with the proposed by McClure et al. [12], who suggested compounds present in molasses can "displace" the defoamer of the interface, implying a decrease in its effect after a given period of time and also indicates a need to add another defoamer dose.

For a concentration of 20 g/L TSR (Fig. 2a), it was observed that from the two commercial defoamers (FV and C10) C10 has highest stability of foam removal. Removal capacity of non-commercial defoamers (CACHA and CACHAP) compared to commercial ones—at 5 min of its addition to the system—was similar, because no significant differences were detected with a P-value (0.3813) greater than 0.05, with a 95% confidence level. After 10 min, commercial defoamers had a more stable effect on foam control and CACHA shows better results than CACHAP.

After 10 and 15 min of analysis at both total sugar concentrations in the medium (20 and 40 g/L), differences were detected between commercial and non-commercial defoamers with values lower than 0.05 (0.0173 and 0.0014 respectively), with 95% confidence. Commercial defoamers FV and C10 had a similar behavior throughout the analysis without showing significant differences between them in “foam removal percentage” (RFR). Figure 2a shows in comparison between commercial defoamers and non-commercial defoamers, after 10 min of starting the test, foam removal percentage is completely differently significant, since FV and C10 continued removing around 20% more than the non-commercial ones. For CACHA and CACHAP defoamers, significant differences were only detected between them at 15 min of addition when they reached values of 22.5 and 10% of foam removal respectively. These results show, at 20 g/L TSR concentration for 15 min, CACHA
can be considered a better option than CACHAP. During the test, the removal values of all the defoamers evaluated were around 50%, which is considered a value below the expected result.

At a concentration of 40 g/L TSR (Fig. 2b), purified filter cake oil (CACHAP) exhibits a foam removal behavior similar to commercial defoamers and superior to crude oil (CACHA). The behavior of the commercial defoamers (FV and C10) at this concentration was similar to that obtained for a concentration of 20 g/L TSR where C10 had the greatest influence on the stability of the foam.

In general, among non-commercial defoamers, the most unfavorable behavior corresponds to CACHA with the lowest foam removal at all times evaluated with significant differences, with P values (0.0131, 0.0079, 0.0059) less than 0.05 for 5, 10 and 15 min respectively, with 95% confidence. CACHAP presented similar values to commercial defoamers after 5 min of their addition, detecting significant differences

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### Table 1 Foam height (mean ± standard deviation) vs time for all the experimental conditions studied (foam height without defoamer were 600 mL and 650 mL for 20 and 40 g/L TRS respectively)

| Foam height (mL) | Time (min) | 20 g/L TSR | 40 g/L TSR |
|------------------|------------|------------|------------|
|                  |            | CACHA      | C10        | FV          | CACHAP      | CACHA | C10 | FV | CACHAP |
| 1                | 50.0±0.0   | 50.0±0.0   | 50.0±0.0   | 50.0±0.0    | 65.0±21.2   | 50.0±0.0 | 50.0±0.0 | 50.0±0.0 |
| 2                | 52.5±3.5   | 50.0±0.0   | 50.0±0.0   | 50.0±0.0    | 75.0±21.2   | 50.0±0.0 | 55.0±7.1 | 50.0±0.0 |
| 3                | 52.5±3.5   | 50.0±0.0   | 50.0±0.0   | 55.0±0.0    | 80.0±14.1   | 55.0±7.1 | 60.0±0.0 | 50.0±0.0 |
| 4                | 57.5±3.5   | 50.0±0.0   | 50.0±0.0   | 57.5±0.0    | 87.5±10.6   | 55.0±7.1 | 62.5±3.5 | 50.0±0.0 |
| 5                | 57.5±3.5   | 52.5±0.0   | 52.5±0.0   | 57.5±3.5    | 95.0±7.1    | 57.5±10.6 | 65.0±3.5 | 60.0±0.0 |
| 6                | 60.0±0.0   | 52.5±3.5   | 55.0±3.5   | 62.5±3.5    | 100.0±0.0   | 65.0±7.1 | 67.5±3.5 | 65.0±7.1 |
| 7                | 65.0±0.0   | 55.0±3.5   | 57.5±0.0   | 65.0±3.5    | 100.0±0.0   | 65.0±7.1 | 70.0±0.0 | 70.0±7.1 |
| 8                | 70.0±0.0   | 57.5±0.0   | 57.5±3.5   | 72.5±7.1    | 100.0±0.0   | 65.0±7.1 | 70.0±0.0 | 75.0±7.1 |
| 9                | 72.5±3.5   | 57.5±3.5   | 60.0±3.5   | 77.5±3.5    | 100.0±0.0   | 65.0±7.1 | 72.5±3.5 | 82.5±3.5 |
| 10               | 72.5±3.5   | 57.5±3.5   | 60.0±7.1   | 82.5±3.5    | 100.0±0.0   | 70.0±7.1 | 77.5±3.5 | 87.5±3.5 |
| 11               | 75.0±7.1   | 57.5±3.5   | 60.0±7.1   | 90.0±3.5    | 100.0±0.0   | 72.5±7.1 | 77.5±3.5 | 95.0±7.1 |
| 12               | 77.5±3.5   | 57.5±3.5   | 60.0±7.1   | 90.0±0.0    | 100.0±0.0   | 75.0±7.1 | 80.0±0.0 | 97.5±3.5 |
| 13               | 77.5±3.5   | 57.5±3.5   | 60.0±7.1   | 90.0±0.0    | 100.0±0.0   | 75.0±7.1 | 80.0±0.0 | 100.0±0.0 |
| 14               | 77.5±3.5   | 57.5±3.5   | 62.5±7.1   | 90.0±0.0    | 100.0±0.0   | 75.0±7.1 | 80.0±0.0 | 105±7.1 |
| 15               | 77.5±3.5   | 57.5±3.5   | 62.5±3.5   | 90.0±0.0    | 100.0±0.0   | 78.0±2.8 | 82.5±3.5 | 105±7.1 |

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Fig. 1 Behavior trend of the foam removal percentage for pure defoamers. a 20 g/L TSR. b 40 g/L TSR. Ca—intercept of corresponding linear regression. Cb—slope of corresponding linear regression.
only after 15 min, time in which their behavior is similar to that obtained for CACHA.

The behavior of the commercial defoamers diluted 1:2 and 1:5 was compared with the non-commercial ones in their pure form under the same working conditions. For the concentration of 20 g/L TSR in the medium at a 1:2 dilution (Fig. 3a), significant differences were found when comparing commercials with CACHA and CACHAP at 10 and 15 min, with a confidence level of 95% and P values less than 0.05 (0.013 and 0.0096 respectively). Greater inestability was observed for commercial defoamers when working with a 1:5 dilution as shown in Fig. 3b, mainly for C10, which, after 15 min, could no longer remove the foam from the system.

Figure 4 represents the same behavior, but for concentrations of 40 g/L TSR. Significant differences were detected between commercial defoamers, especially for the more dilute condition (Fig. 4b). CACHAP showed a favorable response, with better foam removal behavior and higher values than diluted commercial defoamers and CACHA.

**Regression Model Analysis**

Figure 1 shows the results of the adjusted model, with their respective values of $C_{a}$, $C_{b}$ and the correlation coefficient $R^2$. The adjustment of the linear regression model was made in the first 10 min of the test, since a more stable behavior was observed.

From the results obtained with model adjustment, it can be stated that for 20 g/L TSR (Fig. 5a), defoamer with best knock-down effect ($C_{b}$) was CACHAP, since it got highest intercept value. However, results of Simple ANOVA analysis did not detect significant differences between defoamers.
evaluated with a P value greater than 0.05 (0.4614) with 95% confidence, indicating any of them can be employed.

In addition, analyzing Cb value of “foam suppression stability” determination, results indicate C10 was more favorable because it shows highest slope and a P value less than 0.05 (0.0462) was obtained, indicating presence of significant differences of this parameter, with a 95% confidence. When multiple range test was applied with Fisher’s “least significant difference (LSD) procedure”, differences were detected between this defoamer and the non-commercial CACHAP.

In case of 40 g/L TSR, the one with highest stability (Cb) was C10 and respect knock-down effect (Ca), best result was achieved with CACHAP. At this concentration, results of ANOVA analysis did not detect significant differences for Cb and Ca, with P values of 0.2058 and 0.2018 respectively and a 95% confidence level.

Based on the results obtained, the purified filter cake oil can be used successfully as antifoam in this medium. Its application in raw form is not recommended since its effect in suppressing the foam was inferior. In addition, due to its high wax content, it can cause incrustations in the equipment and its application to the environment is difficult, since because it is very dense (pasty) it must be added at a temperature close to 60 °C.

Filter cake oil is a by-product of the sugarcane industry, which is available and its use as a defoamer can be an interesting and economical option for the production of Candida utilis; since it will allow the substitution of commercial defoamers that have a high cost in the market.

**Hansen Solubility Parameters (HSPs)**

A medium where these defoamers should be used is a mixture of different compounds and where yeast has a concentration of 10 g/L. For Hansen solubility parameters calculation of the medium, the amino acids that characterize Candida utilis yeast were taken as a reference and coincide
with those present in either molasses or vinasse, which are the carbon sources normally used as a culture medium in this process; amino acid composition for *Candida utilis* yeast reported by Yañez [24] and Otero and Almazán [25] was assumed. From mass percent and densities of each amino acid, the volumetric percent were obtained by calculating mixture density using trial and error. HSPs of the mixture were calculated from the sum of Hansen’s parameters of each amino acid, affected by the volumetric contribution of each one to the medium. Table 2 shows the amino acids present in the medium and their respective HSPs.

In Table 3 are reported the solvents used for experimental determination of HSP for both commercial defoamers, while in Fig. 5 the Hansen’s sphere of the commercial defoamers are illustrated. HSPs obtained for defoamers studied and the Ra distance as a function of the HSPs of the medium calculated from Eq. 3 are tabulated in Table 4. As can be seen, the “Good solvents” for both defoamer were almost the same; only 2-propanol was a good solvent for CV defoamer and not for FV. Because that, the HSP obtained for both defoamer are quite similar.

Results obtained from Ra values for commercial defoamers are the lowest since their Hansen parameters have similar values. In the case of purified filter cake oil, this value increases because there is a greater difference in polar component, an expected behavior since commercial defoamers studied are designed for its use in this type of fermentation. Low Ra values indicate a high affinity of defoamers to the medium, which complements results obtained in physical tests. About it, C10 has highest affinity with a Ra value of 4.32.

Important is to clarify Hansen parameters were not obtained for crude filter cake oil because it has a high wax content and a variable concentration, so it is expected these factors (δd, δp, δh) will be less than those of purified oil, therefore Ra will be higher and its affinity lower to the medium.

Figure 6 shows relationship between foam volume and Ra values of 5, 10 and 15 min test time. In this case, it coincides with one with lowest value of Ra. C10 was the defoamer that maintains lowest foam volume, which also complements the criterion that the lower the value of Ra, the greater the affinity with the medium. This aspect corroborates Kato et al. [13] proposition where they state “use of the Ra calculation could be another criterion for selection of best antifoam”. Another aspect corroborated in this test is existing similarity in foam suppressing behavior between defoamers studied and use of purified filter cake oil, meaning it may be an option to consider for its use in SCP technology.

### Conclusions

The purified filter cake oil was determined to be an effective product for use as antifoam. From the analysis carried out, it was obtained that this oil presented the highest knock down effect and C10 presented the highest stability in foam suppression for both concentrations of TRS evaluated (20 and 40 g/L), although the foam removal varies depending on of the sugar concentration of the medium. The determination of the Hansen solubility parameters (HSP) and the distance between them (Ra) corroborates the effectiveness of the use of this by-product of the sugar industry to suppress the foam in the studied medium.
Table 3 Experimental results of commercial defoamers evaluation for HSP determination

| No  | Solvent          | \(\delta_d\) (MPa)^{1/2} | \(\delta_p\) (MPa)^{1/2} | \(\delta_h\) (MPa)^{1/2} | Score C10 | Score FV | RED C10 | RED FV |
|-----|------------------|---------------------------|---------------------------|---------------------------|------------|----------|---------|--------|
| 92  | 1-Butanol        | 16                        | 5.7                       | 15.8                      | 1          | 1        | 0.865   | 0.997  |
| 197 | 1-Decanol        | 16                        | 4.7                       | 10.5                      | 0          | 0        | 1.712   | 1.907  |
| 930 | 1-Hexanol        | 15.9                      | 5.8                       | 12.5                      | 1          | 1        | 0.836   | 0.948  |
| 552 | 1-Pentanol       | 15.9                      | 5.9                       | 13.9                      | 1          | 1        | 0.493   | 0.591  |
| 93  | 2-Butanol        | 15.8                      | 5.7                       | 14.5                      | 1          | 1        | 0.507   | 0.602  |
| 732 | 2-Methyl-2-Butanol | 15.3                    | 6.1                       | 13.3                      | 1          | 1        | 0.455   | 0.488  |
| 570 | 2-Propanol       | 15.8                      | 6.1                       | 16.4                      | 1          | 0        | 0.943   | 1.072  |
| 5   | Acetic Acid      | 14.5                      | 8                         | 13.5                      | 1          | 1        | 0.942   | 0.989  |
| 10  | Acetonitrile     | 15.3                      | 18                        | 6.1                       | 0          | 0        | 5.441   | 6.01   |
| 52  | Benzene          | 18.4                      | 0                         | 2                         | 0          | 0        | 5.94    | 6.595  |
| 58  | Benzyl Alcohol   | 18.4                      | 6.3                       | 13.7                      | 0          | 0        | 2.319   | 2.625  |
| 122 | Carbon Tetrachloride | 17.8                    | 0                         | 0.6                       | 0          | 0        | 6.237   | 6.918  |
| 156 | Chloroform       | 17.8                      | 3.1                       | 5.7                       | 0          | 0        | 4.068   | 4.525  |
| 182 | Cyclohexanol     | 17.4                      | 4.1                       | 13.5                      | 0          | 0        | 1.863   | 2.114  |
| 187 | Cyclopentane     | 16.4                      | 0                         | 1.8                       | 0          | 0        | 5.592   | 6.194  |
| 254 | Diethyl Carbonate | 15.1                      | 6.3                       | 3.5                       | 0          | 0        | 4.213   | 4.651  |
| 255 | Diethyl Ether    | 14.5                      | 2.9                       | 4.6                       | 0          | 0        | 4.131   | 4.558  |
| 297 | Dimethyl Formamide | 17.4                    | 13.7                      | 11.3                      | 0          | 0        | 3.32    | 3.692  |
| 303 | Dimethyl Sulfoxide | 18.4                    | 16.4                      | 10.2                      | 0          | 0        | 4.701   | 5.223  |
| 325 | Ethanol          | 15.8                      | 8.8                       | 19.4                      | 0          | 0        | 2.213   | 2.462  |
| 328 | Ethyl Acetate    | 15.8                      | 5.3                       | 7.2                       | 0          | 0        | 2.817   | 3.117  |
| 368 | Ethylene Glycol  | 17                        | 11                        | 26                        | 0          | 0        | 5.073   | 5.635  |
| 406 | Glycerol         | 17.4                      | 11.3                      | 27.2                      | 0          | 0        | 5.621   | 6.244  |
| 431 | Isobutyl Alcohol | 15.1                      | 5.7                       | 15.9                      | 1          | 1        | 0.841   | 0.924  |
| 456 | Methanol         | 14.7                      | 12.3                      | 22.3                      | 0          | 0        | 3.904   | 4.316  |
| 524 | Dichloromethane  | 17                        | 7.3                       | 7.1                       | 0          | 0        | 3.042   | 3.382  |
| 540 | Octane           | 15.5                      | 0                         | 0                         | 0          | 0        | 6.174   | 6.83   |
| 697 | p-Xylene         | 17.8                      | 1                         | 3.1                       | 0          | 0        | 5.24    | 5.817  |
| 598 | Pyridine         | 19                        | 8.8                       | 5.9                       | 0          | 0        | 4.353   | 4.848  |
| 637 | Toluene          | 18                        | 0.1                       | 0                         | 0          | 0        | 5.596   | 6.211  |
| 649 | Trichloroethylene | 18                        | 3.1                       | 5.3                       | 0          | 0        | 4.269   | 4.748  |
| 696 | Water            | 15.5                      | 16                        | 42.3                      | 0          | 0        | 11.622  | 12.871 |

Good (score 1) and bad (score 0) solvents test

Table 4 Hansen solubility parameters and distance Ra determined in relation to the HSPs obtained for the medium

| Medium                      | \(\delta_d\) (MPa)^{1/2} | \(\delta_p\) (MPa)^{1/2} | \(\delta_h\) (MPa)^{1/2} | Ra (MPa)^{1/2} |
|-----------------------------|---------------------------|---------------------------|---------------------------|----------------|
| Candida utilis yeast        | 17.4                      | 7.67                      | 15.91                     | –              |
| Defoamer                    |                           |                           |                           |                |
| C10                         | 15.47                     | 6.76                      | 14.19                     | 4.32           |
| FV                          | 15.40                     | 6.78                      | 14.17                     | 4.46           |
| CACHAP                      | 16.24                     | 3.21                      | 10.34                     | 7.51           |

\(\delta_d, \delta_p, \delta_h\) Hansen solubility parameter; Ra: distance between HSPs
Fig. 6 Relationship between distance \( Ra \) and Foam volume. \( a \) 20 g/L TSR. \( b \) 40 g/L TSR. \( \square \) 5 min, \( \square \) 10 min, \( \square \) 15 min

Acknowledgements The authors gratefully acknowledge to Professor Gustavo Saura Laria for his technical assistance.

Author Contributions Not applicable.

Funding Not applicable.

Data Availability The data used in the article is available if required.

Code Availability HSPiP software version 5.2.0.

Declarations

Conflict of interest The authors declare no conflict of interest.

Ethical Approval Not applicable.

Consent to Participate The authors give their consent to participate.

Consent for Publication The authors give their consent for the publication of the article.

References

1. Nielsen, J.C., De Oliveira, F.S., Gundelund, T., Thykær, J., Workman, C.T., Olitta, T.: Industrial antifoam agents impair ethanol fermentation and induce stress responses in yeast cells. Appl. Microbiol. Biotechnol. 101, 8237–8248 (2017). https://doi.org/10.1007/s00253-017-8548-2
2. Cevada, E., Roos, K., Álvarez, F., Carlotti, S., Vázquez, F.: High molar mass polyethers as defoamers of heavy crude oil. Fuel 221, 447–454 (2018). https://doi.org/10.1016/j.fuel.2018.02.136
3. Saura, G., Otero, M.A., Martínez, J.A., Fundora, N., Reyes, E., Vazallo, M.C., Almazán, O.: Propagation of yeast biomass from distillery wastes. Process and product evaluation. Int. Sugar J. 105, 36–39 (2003)
4. García, R., Izquierdo, Y., Ribas, M., Tortoló, K., Ibañez, M., León, O., Saura, M., Saura, G.: Effects of urea supplementation on \textit{Candida utilis} biomass production from distillery waste. Waste Biomass Valoriz. 5, 119–124 (2014). https://doi.org/10.1007/s12649-013-9209-z
5. Condé, B.C., Bouchard, E., Culbert, J.A., Wilkinson, K.L., Fuentes, S., Howell, K.S.: Soluble protein and amino acid content affects the foam quality of sparkling wine. J. Agric. Food Chem. (2017). https://doi.org/10.1021/acs.jafc.7b02675
6. Denkov, N.D., Marinova, K.G., Tcholakova, S.S.: Mechanistic understanding of the modes of action of foam control agents. Adv. Colloid Interface Sci. 206, 57–67 (2014). https://doi.org/10.1016/j.cis.2013.08.004
7. Gélinas, P.: Aeration and foam control in Baker’s yeast production: mapping patents. Compr. Rev. Food Sci. Food Saf. 15, 371–391 (2016). https://doi.org/10.1111/1541-4337.12188
8. Melo-Espinosa, E.A., Sánchez-Borroto, Y., Errasti, M., Piloto-Rodríguez, R., Sierens, R., Roger-Riba, J., Christopher-Hansen, A.: Surface tension prediction of vegetable oils using artificial neural networks and multiple linear regression. Energy Proced. 57, 886–895 (2014). https://doi.org/10.1016/j.egypro.2014.10.298
9. Sahasrabudhe, S.N., Rodríguez-Martinez, V., O’Meara, M., Farakas, B.E.: Density, viscosity, and surface tension of five vegetable oils at elevated temperatures: measurement and modeling. Int. J. Food Prop. 20(S2), S1965–S1981 (2017). https://doi.org/10.1080/10942912.2017.1360905
10. Kougias, P.G., Tsapekos, P., Boe, K., Angelidaki, I.: Antifoaming effect of chemical compounds in manure biogas reactors. Water Res. 47(16), 6280–6288 (2013). https://doi.org/10.1016/j.watres.2016.11.033
11. Cevada, E., Flores, C.A., López, A., Álvarez, F., Vázquez, F.: Study of the thermal stability of jojoba oil used as antifoaming agent in petroleum industry. J. Therm. Anal. Calorim. (2016). https://doi.org/10.1007/s10973-016-5911-y
12. McClure, D.D., Lamy, M., Black, L., Kavanagh, J., Barton, G.W.: An experimental investigation into the behaviour of antifoaming agents. Chem. Eng. Sci. 160, 269–274 (2017). https://doi.org/10.1016/j.ces.2016.11.033
13. Kato, Y., Osawa, T., Yoshihara, M., Fujii, H., Tsutsumi, S., Yamamoto, H.: Evaluation of the antifoaming effect using Hansen solubility parameters. ACS Omega 5, 5684–5690 (2020). https://doi.org/10.1021/acsomega.9b03567
14. Nunes Pereira, C., Cañete Vebber, G.: A novel semi-empirical method for adjusting solubility parameters to surface tension based on the use of Stefan’s rule. J. Mol. Liq. 272, 520–527 (2018). https://doi.org/10.1016/j.molliq.2018.09.116
15. Nunes Pereira, C., Cañete Vebber, G., Mauler, R.S., Bianchi, O.: DiPEVa, an interactive method for adjusting the three-dimensional solubility parameters to surface tension. J. Mol. Liq. (2021). https://doi.org/10.1016/j.molliq.2021.116799. (in press)

16. Montano, R., Díaz de Arce, C., García, C.: Efecto antiespumante comparativo de esteres de girasol y cachaza respectivamente. ICIDCA Sobre deriv. caña azúcar 3, 52–59 (1993)

17. Soomro, R.K., Sherazi, S.T.H.: Extraction and characterization of seed oil waxes by using chromatographic techniques. Int. J. Ind. Chem. 4, 1–7 (2013)

18. Chalapud, M.C., Baümler, E.R., Carelli, A.A.: Characterization of waxes and residual oil recovered from sunflower oil winterization waste. Eur. J. Lipid Sci. Technol. (2016). https://doi.org/10.1002/ejlt.201500608

19. Porto, T., Lopes, R.: Designing biotechnological processes to reduce emulsions formation and improve oil recovery: study of antifoams application. Biochem. Eng. J. (2020). https://doi.org/10.1016/j.bej.2020.107745

20. Reinoso, O.: El aceite de cera de cachaza de la caña de azúcar como fuente de sustancias naturales o precursoras de ellas. CENIC, Ciencias Químicas 35(1), 29–31 (2004)

21. Silveira, R.: Estudio da viabilidade técnica da produção de biodiesel a partir do óleo de cera de cana-de-açúcar. Dissertação apresentada para a obtenção do título de Mestre em Tecnologia de Alimentos Faculdade de Engenharia de Alimentos da Universidade Estadual de Campinas. Sao Paulo. Brasil. p. 113 (2011)

22. Hernández, E., Díaz, M., Pérez, K.: Determination of Hansen solubility parameters for sugar cane oil. Use of ethanol in sugar-cane wax refining. Grasas aceites 72(2), e408 (2020). https://doi.org/10.3989/gya.0326201

23. Abbott, S., Yamamoto, H.: HSPiP Software, 5th edn. 5.2.05 (2015)

24. Yañez, E., Ballester, D., Fernández, N., Gatths, V., Monckeberg, F.: Chemical composition of Candida utilis and the biological quality of the yeast protein. J. Sci. Food Agric. 23, 581–586 (1972)

25. Otero, M.A.; Almazán, O.: Las levaduras como base de una industria. Diferentes aplicaciones. Editorial Académica Española. Alemania (2012)

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