Influence of the addition of dairy cow manure as cosubstrate during the energetic valorization of cheese whey by psychrophilic anaerobic digestion

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Introduction

Cheese whey (CW) and dairy cow manure (DM) are agro-industrial residues, the main by-products of the dairy chain. The CW is produced at a rate of 9kg of CW kg of cheese produced, it has an acidic pH and high concentrations of organic matter. While for the DM, from a single animal an average of 48 kg/day is generated, it also has a pH close to neutrality and is rich in nutrients such as nitrogen and phosphorus. Both waste are recoverable and usable through biological processes such as anaerobic codigestion (AcoD), which contributes to the efficient use of residues from the dairy chain within dairy farms and the reduction of the use of fossil fuels (Villarroel-Schneider et al., 2020). AcoD is a process through which it is possible to recover nutrients and carbon, in addition, it is not only possible to increase biogas yields but also contribute to mitigating the emission of greenhouse gases (GHG), since it is estimated that around 53% of methane emissions are derived from manure and come from the DM (Glover et al., 2023). However, most tests and scale reactors are carried out at mesophilic temperatures, which implies an energy expense that should be eliminated if the technology is to be implemented in cold regions such as those of the Andean highlands (Martí-Herrero et al., 2022). However, for the AcoD process to be successful, it is necessary to establish the mixing ratio and organic load that contribute to increasing biogas production, that is, to generate a synergistic effect. Authors such as Jaimes-Estévez et al., (2020) have studied the mixing ratio of these residues, however they have only analyzed the mixing ratio and the substrate inoculum ratio (ISR) between 1 and 2 but not represented from the perspective of the organic load. Additionally, studies have overlooked that at psychrophilic temperatures the charge must be analyzed since the degradation is different compared to mesophilic temperatures. Therefore, this work evaluated the AcoD between CW and DM under different mixing proportions and inoculum substrate ratios (ISR) but represented from the point of view of organic load; in order to identify the treatment capacity of AcoD in a psychrophilic regime.

Methodology

The CW and DM were obtained from a small dairy farm located in the municipality of Ubaté (Colombia) that has around 700 dairy cows that produce an average of 1200 L of milk/day; there, between 800 and 100 L of CW/day are obtained as a by-product of cheese making. The CW composite sample used for the assays was made up of three subsamples taken from different days of a week. The CM was taken directly from the pasture after the milking of the cows, where a sample of manure from different animals is obtained. The inoculum was taken from an anaerobic digester of a dairy company that processes dairy waste in the same region. The CW, CM, and inoculum samples were characterized in terms of total solids (TS) and volatile solids (VS), soluble oxygen chemical demand (sCOD), and total and bicarbonate alkalinity, according to APHA, (2017).

BMP assays were developed in 250 mL Duran® vials sealed with a bromobutyl stopper and maintained at a psychrophilic temperature (20°C±0.1), using the gas density method (Justesen et al., 2019), a positive control (cellulose) and a blank (inoculum only) were included (Holliger et al., 2021). The Working Volume was based on the ISR used, using 110 mL of inoculum to all reactors. A central composite design was developed to analyse the simultaneous incidence of the CW:CM (w/w) mixing ratio (X_1) and the added load (X_2), which were analysed through the response surface methodology (RSM) (Montgomery, et al., 2009) using MINITAB software. The experiment was run for 43 days. Each factor under analysis was evaluated at five levels corresponding to minimum, intermediate, and maximum values (the normalized values were $-\sqrt{2}$, -1, 0, +1, and $\sqrt{2}$, respectively, ach in quadruplicate) that corresponded to values reported in the literature (Jaimes-Estévez et al., 2022). Table 1 presents the experimental design, which was done in the MiniTab® software in its free version.

Table 1. Experimental Design.

ID	X_1	X_2	Mix CW:CM (%)	OL (gVS/L)	ID	X_1	X_2	Mix CW:CM (%)	OL (gVS/L)
A	1	1	15:85	0.53	F	0	0	50:50	0.75
B	1	-1	15:85	1.26	G	$\sqrt{2}$	0	00:100	0.75
C	0	$-\sqrt{2}$	50:50	0.47	H	-1	-1	85:15	1.26
D	-1	1	85:15	0.53	I	$-\sqrt{2}$	0	100:00	0.75
E	0	$-\sqrt{2}$	50:50	1.80					

Results and discussion

Figure 1 shows the response surface generated from the nine experimental configurations. The proportion that generates an antagonistic effect, that is, where there was less production, is between 0 and 45% of CW and 1.4 and 1.75 gVS/L approximately. This is because the highest proportion would be DM, a substrate with a high presence of lignocellulosic material that is difficult to degrade anaerobically under psychrophilic conditions (Usman Khan and Kiaer Ahring, 2021). On the contrary, the synergistic effect on production would be between approximately 42 and 95%, that is, in fractions with a greater amount of CW, due to the high concentration of available organic matter (Mata-Alvarez et al., 2014), for its part, the organic load varies between 0.5-1.4 gVS/L. Therefore, an optimization was carried out maximizing biomethane production, finding that the best ratio in percentage is 65:35 (CW:DM) and the load 0.6 gVS/L (ISR=3.1) finding a maximum of 562 mL_{CH4}/gSV. The quadratic regression identified that the mixing ratio is the variable that most affects the process (p=0.002) considering the p-value of the load (0.287). Similar ratio (70:30 w/w) to that reported by Jaimes-Estévez et al. (2020), but that differs in relation to the ISR, because they evaluated a maximum ISR of 2.0 obtaining 0.42 mL_{CH4}/gSV, while this study evaluated ISR up to 4.0 mL. The values also differ from studies such as that of Bertin et al., (2013) who found lower production at 35°C (310 mL_{CH4}/gSV), which could perhaps be attributed to the accumulation of VFAs, as a consequence of the higher activity at this temperature.The above indicates that psychrophilic temperatures are better with low OL and high ISR since they do not degrade at the same speed as mesophilic ones. In addition, it is necessary to continue investigating around low temperatures (≤20 °C) and low-cost reactors, since many industries, such as dairy, are developed in sectors such as the highlands and lack the economic resources to develop large investments that allow them to make their farms sustainable.

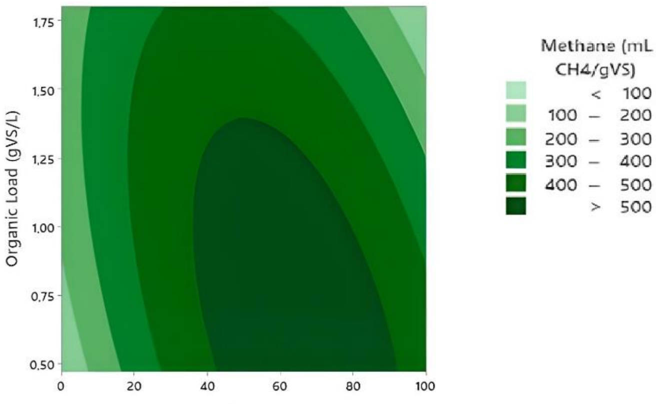

Figure 1 Organic load as a function of the proportion in the proportion of CW

Conclusion

The best mixing ratio is 65:35 (CW:DM) using a load of 0.6 gVS/L, under these conditions the process is more stable due to the contribution of alkalinity that the DM makes to the VFAs that may occur due to the high degradability that CW presents. Psychrophilic temperatures are adequate to develop digestion processes with low organic loads and high substrate inoculum ratios, since metabolic activity is slower, and this leads to no accumulation of intermediate products that affect the process. In addition, these results are also useful for making decisions regarding the availability of substrates, for example, if the objective is to treat larger quantities of substrate or to prioritise the production of biomethane.

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