# Utilization of rice crop residuals for biogas production through anaerobic digestion

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The population of earth is expected to rise to 10.4 billion by the end of the century, while the global energy demand due to rapid and expansive industrialization will be increased by one third by 2040 (Paudel et al., 2017). Fossil fuels provide almost 88% of the global energy although they are expected to be depleted in the next few decades (Algapani et al., 2019). In addition, their use is responsible for greenhouse gas emissions which lead to global warming and climate change. Thus, the adoption of new and environmentally friendly energy sources is necessary. Anaerobic digestion (AD) of organic residues and wastes from agriculture such a rice straw (RS) and swine slurry (SS) is a viable solution (Ayinla et al., 2019). AD can be characterized as mono-digestion when a single substrate is used and as co-digestion when more than one substrates are utilized (Karki et al., 2021). However, due to the physicochemical characteristics of RS and SS, the mono-digestion of each feedstock separately can result in excessive acids accumulation or ammonia. On the contrary, the co-digestion of RS and SS can attain a nutrient balance for microorganisms, achieving a suitable operational pH, and improve microbial activity, thus higher efficacy.

The present study was conducted to evaluate fourteen (14) methods for rice biomass pre-treatment (Table 1) and use the most promising to determine the optimal ratio of pre-treated rice straw (p-RS) and SS in co-digestion batch experiments. The aim was to assess if the co-digestion of p-RS and SS can increase methane production, compared with the mono-digestion of SS, and whether they can be used in a continuous stir-tanked reactor (CSTR).

Table 1. Conditions applied for rice straw pre-treatment.

| | |
|---|---|
| | Rice Straw |
| 1 | Manual (rice straw was chopped 2-3 cm in length with paper scissors) (Control) |
| 2 | Mechanical (rice straw was grinded by a laboratory mill in pieces of 0.5 mm) |
| | Thermal |
| 3 | Manual + LD, 130 $^0$C for 30 min (30DIG130RAW) |
| 4 | Manual + LD, 130 $^0$C for 60 min (60DIG130RAW) |
| 5 | Manual + LD, 190 $^0$C for 30 min (30DIG190RAW) |
| 6 | Manual + LD, 190 0C for 60 min (60DIG190RAW) |
| 7 | Mechanical + LD, 130 $^0$C for 30 min (30DIG130MEC) |
| 8 | Mechanical + LD, 130 $^0$C for 60 min (60DIG130MEC) |
| 9 | Mechanical + LD, 190 $^0$C for 30 min (30DIG190MEC) |
| 10 | Mechanical + LD, 190 $^0$C for 60 min (60DIG190MEC) |
| | Thermo-chemical |
| 11 | Manual + NaOH 4% w/w TS at 121 $^0$C for 20 min (4TS121RAW) |
| 12 | Manual + NaOH 6% w/w TS at 55 $^0$C for 24 h (6TS55RAW) |
| 13 | Mechanical + NaOH 4% w/w TS at 121 $^0$C for 20 min (4TS121MEC) |
| 14 | Mechanical + NaOH 6% w/w TS at 55 $^0$C for 24 h (6TS55MEC) |

* LD = liquid fraction from a commercial biogas reactor.

The examined methods for the pre-treatment of RS, included: mechanical pre-treatment (manually chopped to 2-3 cm or grinded by a laboratory mill in pieces of 0.5 mm), thermal and thermo-chemical hydrolysis (Table 1). For comparison purposes, the chopped RS was used as the control. The thermal pre-treatments were conducted using the liquid fraction (LD) from a commercial biogas plant (Biogas Lagada SA), while thermo-chemical pre-treatments were conducted using NaOH 1 M. Regarding the co-digestion experiments, five ratios of p-RS:SS (% w/v) were investigated. Specifically, the first treatment comprised 50% SS and 50% p-RS (50SS), the second 60%

SS and 40% p-RS (60SS), the third 70% SS and 30% p-RS (70SS), the fourth 80% SS and 20% p-RS (80SS) and the fifth 90% SS and 10% p-RS (90SS). The last treatment was exclusively comprised from SS (100SS) and served as the control. Each treatment was replicated three times. The efficiency of each pretreatment in terms of methane productivity was evaluated by Biochemical Methane Potential (BMP) assays. The same methodology was also applied during the co-digestion experiments and proper comparisons were performed in terms of methane productivity between the samples in order to identify the optimal p-RS:SS ratio. BMP testing, was set according to the methodology described in the BMP protocol (Angelidaki et al., 2009). The amount of produced methane, contained within the biogas, was measured regularly using gas chromatography until no further methane was generated. The RS was collected from the Kalochori area, near the city of Thessaloniki, while the SS was collected from a commercial biogas plant (Biogas Lagada SA). Analysis of variance was performed to detect and separate mean treatments differences at *p*-value < 0.05, using the MSTAT-C ver. 1.41 statistical programme.

As far as the rice biomass pre-treatment experiments are concerned, the control (chopped rice biomass, see Table 1) produced 279.74 mL $CH_4$/g VS. Among the methods examined, only four (4) contributed to statistically significant incremental changes in methane yield, ranging from 13 to 15%. These methods were all thermo-chemical. However, given that the differences among these methods appeared to be insignificant, the pre-treatment chosen for the continuation of the experimental procedure was the 6TS55RAW. The selection was made considering that this method was less energy demanding compared to the other three (6TS55MEC, 4TS121RAW, 4TS121MEC), since rice straw was chopped manually and the temperature required was 55 $^0$C. On the contrary, the other three required either the use of a laboratory mill to grind the rice straw or high temperature (121 $^0$C). These results appear to be in line with those presented by Tsapekos et al. (2016), who investigated the effect of mechanical and thermo-chemical pre-treatment on digested manure biofibers.

According to the results obtained from the co-digestion experiments, the treatment that led to the most significant increment in methane yield (59%) compared to the untreated sample (100SS), was the 50SS (Figure 1B). Following, 60SS and 70SS produced 44 and 41% more methane, respectively, while 80SS and 90SS presented the lowest but significant increments in methane yield, equal to 33 and 30% (Figure 1B). Similar conclusions were drawn from another study by Darwin et al. (2014). According to their research, rice straw co-digested with digested swine manure (DSM) increased methane yield when compared with the mono-digestion of DSM.

On accounts of the above, the inference reached was that the pre-treatment of the recalcitrant rice biomass with NaOH enhances its biodegradability. In addition, it was concluded that the co-digestion with SS increases methane production compared to the mono-digestion of the SS, without impairing the methanogenesis procedure. Currently, the experiments are ongoing, and the optimal ratio of p-RS and SS has yet to be tested in a CSTR reactor. The results will be available upon the time of the conference.

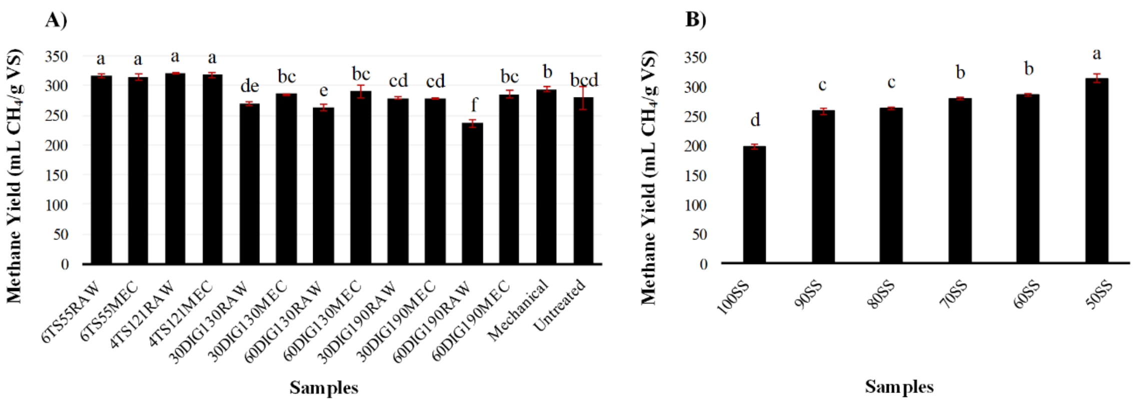


**Figure 1.** (A) Bar chart of statistically significant differences between the pre-treated samples, regarding methane yield; (B) Bar chart of statistically significant differences between the co-digestion samples, regarding methane yield. Different letters indicate differences between samples at a=0.05.

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