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### Data Article

# Auxiliary energy-assisted biodiesel production data from solid food waste oil

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#### ABSTRACT

A number of samples from solid food waste oil (SFWO) from different restaurants have been collected. Data regarding fatty acid profile, acid value, water content and kinematic viscosity were used for characterization purposes. Response surface methodology data has been used to carry out conventional transesterification optimization. The quality of the final product has been checked following the European biodiesel standard EN14214. To compare conventional and ultrasound-assisted transesterification results, energy consumption and reaction time data have been gathered. More information and result interpretation may be found in "Optimization of solid food waste oil biodiesel by ultrasound assisted transesterification" [1].

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## Specifications table

|                                |   |
|--------------------------------|---|
| Subject                        | Renewable Energy, Sustainability and the Environment  |
| Specific subject area          | Solid food waste recycling to produce biodiesel through ultrasound-assisted low-cost transesterification  |
| Type of data                   | Tables<br>Figures<br>Excel file   |
| How data were acquired         | Gas chromatography, analytical analysis, Box–Behnken design, response surface methodology, mass spectrometry.<br>Instruments: Perkin Elmer GC model Clarus 500, Rancimat Metrohm, Alcor CRT-160 by PAC, IKA bomb calorimeter, capillary-type viscometer Cannon-Fenske size 150, Karl Fischer titrator model DL32 Mettler Toledo, Seta Flash series 3 plus, HCO 342 Herzog by PAC, Statgraphics Centurion XVI software, QSonica LLC, Fluke power analyzers models 435 and 43B, Perkin Elmer mass spectrometer ICP-MS NexION 350X |
| Data format                    | Raw and analyzed  |
| Parameters for data collection | Restaurants showing different customer habits and tastes (grill, fine dining, campus cafeteria and Italian restaurant) were selected. Seasonal implications were also considered. Only organic fraction was used for subsequent analysis.   |
| Description of data collection | A set of 30 solid food waste oil samples were collected from four local restaurants. Sampling was conducted on random days during four months. Samples were homogenized and inorganic residues were discarded. Subsequently, organic fraction was milled, lyophilized for three days and stored at 4 °C.  |
| Data source location           | City/Town/Region: Cordoba<br>Country: Spain   |
| Data accessibility             | With the article  |
| Related research article       | M. Carmona-Cabello, J. Sáez-Bastante, S. Pinzi, M.P. Dorado, Optimization of solid food waste oil biodiesel by ultrasound-assisted transesterification, Fuel, <a href="https://doi.org/10.1016/j.fuel.2019.115817">https://doi.org/10.1016/j.fuel.2019.115817</a>   |

## Value of the Data

- These data provide physico-chemical and energy properties of a variety of restaurant organic residues that may be used to provide a recycling model through the concept of a biorefinery.
- Scientists working in biorefinery design and development may benefit from these data, besides biodiesel manufacturers.
- These data may be part of a wider pool of data, including agrifood residues, that may be used to design a valorization strategy.

## 1. Data description

In the excel file SFWO brief.xlsx, sheet no. 1, raw data related to characterization of solid food waste oil (SFWO), belonging to solid residues from tested restaurants, is provided [1]. Information shows fatty acid content and distribution, besides length of chain (LC) and total unsaturation degree (TU). Characterization also includes raw data of some of the most relevant physico-chemical properties (considering the feasibility of the conversion of this oil into biodiesel), namely acid value, water content and kinematic viscosity (Table 1).

For classification purposes, the comparison between a wide variety of oils and SFWO is provided by principal component analysis, shown in Table 2. Principal component 1 (PC1) includes oils with a combination of C16:0 and C18:1 fatty acids, while PC2 includes only the presence of C18:2.

Transesterification was preceded by acid esterification, due to the high oil acid value. Raw data about evolution and reduction of the acid value during esterification is shown in Table 3.

**Table 1**

Sample physical and chemical properties. SD: standard deviation.

|          | Acid value, AV | Water content | Kinematic viscosity |
|----------|----------------|---------------|---------------------|
|          | mgKOH/g        | ppm           | mm <sup>2</sup> /s  |
| Sample 1 | 7.59           | 500           | 24.60               |
| Sample 2 | 7.47           | 479           | 24.59               |
| Sample3  | 7.54           | 584           | 24.61               |
| Average  | 7.53           | 521           | 24.60               |
| SD       | 0.06           | 65            | 0.01                |

**Table 2**

Principal component analysis. PC1: combination of C16:0 and C18:1; PC2: C18:2.

| RAW MATERIALS               |   | PC1           | PC2      |
|-----------------------------|---|---------------|----------|
| Common name                 | Binomial nomenclature   | C16:0 & C18:1 | C18:2    |
| Solid food waste oil (SFWO) | -   | -0.01030      | 0.38063  |
| Yellow grease               | -   | -0.84551      | 0.31902  |
| Brown grease                | -   | -0.58101      | 0.25712  |
| Sunflower oil               | <i>Helianthus annuus</i> oil                                    | 2.15595       | -0.40731 |
| Rice bran oil               | <i>Oryza sativa</i> bran oil                                    | 0.74175       | 0.37730  |
| Corn oil                    | <i>Zea mays</i> oil   | 1.34799       | 0.05043  |
| Rapeseed oil                | <i>Brassica napus</i> oil                                       | 0.09923       | 0.75998  |
| Crambe oil                  | <i>Crambe cordifolia</i> and <i>C. abyssinica</i> oils          | -0.44872      | -0.58297 |
| Canola oil                  | <i>Brassica rapa</i> , <i>B. juncea</i> and <i>B. napus</i> oil | -0.10663      | 0.90778  |
| Sesame oil                  | <i>Sesamum indicum</i> oil                                      | 0.52511       | 0.55850  |
| Peanut oil                  | <i>Arachis hypogaea</i> oil                                     | 0.32027       | 0.58830  |
| Coconut oil                 | <i>Cocos nucifera</i> oil                                       | -1.11843      | -1.38740 |
| Olive oil                   | <i>Olea europaea</i> oil  | -0.75998      | 1.41586  |
| Jatropha oil                | <i>Jatropha curcas</i> oil                                      | 0.68927       | 0.15252  |
| Almond oil                  | <i>Prunus dulcis</i> oil  | 1.25989       | 0.06333  |
| Castor oil                  | <i>Ricinus communis</i> oil                                     | -2.71850      | -2.83953 |
| Linseed oil                 | <i>Linum usitatissimum</i> oil                                  | -0.10601      | -0.99837 |
| Walnut oil                  | <i>Juglans regia</i> oil  | 1.92387       | -0.74607 |
| Walnut kernel oil           |   | 1.76091       | -0.71735 |
| Poppyseed oil               | <i>Papaver somniferum</i> oil                                   | 2.29905       | -0.59814 |
| Soybean oil                 | <i>Glicine max</i> oil  | 1.30947       | -0.71286 |
| Cotton oil                  | <i>Gossypium hirsutum</i> oil                                   | 1.70090       | -0.65943 |
| Groundnut oil               | <i>Arachis villosulicarpa</i> oil                               | 0.28692       | 0.48147  |
| Hazelnut oil                | <i>Corylus avellane</i> oil                                     | -0.16128      | 1.93525  |
| Neem oil                    | <i>Azadirachta indica</i> oil                                   | -0.71399      | 0.56460  |
| Karanja oil                 | <i>Millettia pinnata</i> oil                                    | -0.77982      | 0.75303  |
| Mustard                     | <i>Sinapis alba</i> oil   | -0.39443      | -1.23350 |
| Abyssinian mustard          | <i>Brassica carinata</i> oil                                    | -0.17655      | -1.28249 |

Sheet no. 2 (excel file SFWO brief.xlsx) shows gas chromatography results (raw and analysed data) from the analysis carried out following a design of experiments (DOE) for SFWO transesterification. Fatty acid content was provided, besides ester yield, before and after cleaning process. Table 4 includes resulting fatty acid methyl ester (FAME) yield (measured by gas chromatography) under both conventional transesterification (CT) and ultrasound-assisted transesterification (UT), including standard deviation (SD).

Table 5 exhibits the trend of glyceride (mono-, di- and triglycerides) concentration vs. time, during ultrasound-assisted transesterification. Calibration curves are also provided (Table 6 and Figs. 1–4).

Table 7 show energy analysis to compare energy consumption under both conditions, namely conventional and ultrasound-assisted transesterification. For this purpose, a new “energy use index” parameter has been defined (Eq. (1)).

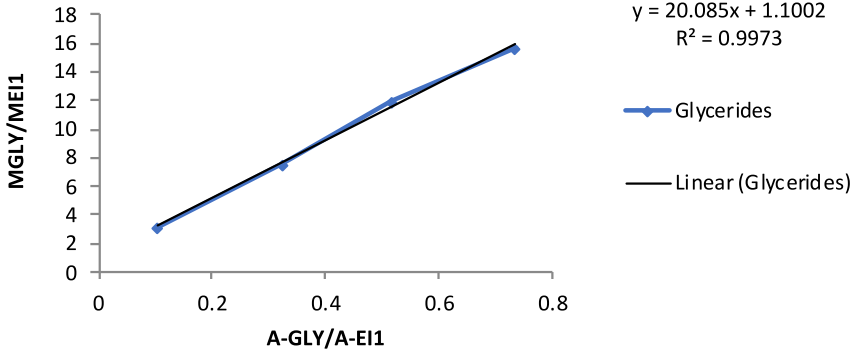
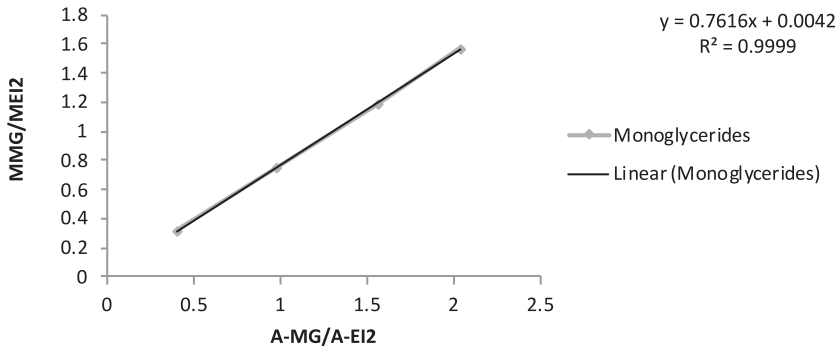
$$EUI = LHV / CE$$

(1)

**Table 3**

Evolution of acid value during acid esterification (pre-treatment before transesterification) of solid food waste oil (SFWO).

| Acid value (mg KOH/mg) | Free fatty acid content (% w/w) |
|------------------------|---------------------------------|
| 7.53                   | 3.765                           |
| 2.19                   | 1.095                           |
| 1.78                   | 0.890                           |
| 1.24                   | 0.620                           |
| 0.61                   | 0.305                           |
| 0.38                   | 0.190                           |
| 0.31                   | 0.155                           |
| 0.28                   | 0.140                           |

**Fig. 1.** Glyceride content calibration curve. MGLY: glyceride concentration; MEI1: internal standard concentration; A-GLY: glyceride area; A-EI1: internal standard area.**Fig. 2.** Monoglyceride content calibration curve. MMG: monoglyceride concentration; MEI2: internal standard concentration; A-MG: monoglyceride area; A-EI2: internal standard area.

Where, LHV is low calorific value (J/g) and CE is the amount of energy per mass unit required for its synthesis (J/g). Table 8 includes biodiesel properties, following European biodiesel standard EN 14,214. Finally, Table 9 includes a detailed quantitative analysis of metal content by inductivity coupled plasma mass spectrometry (ICP-MS).

## 2. Experimental design, materials, and methods

After collecting SFW samples from four restaurants during several weeks and seasonally (see [1] for more details) and once inorganic residues were discarded (plastics, etc.) they were mixed

**Table 4**

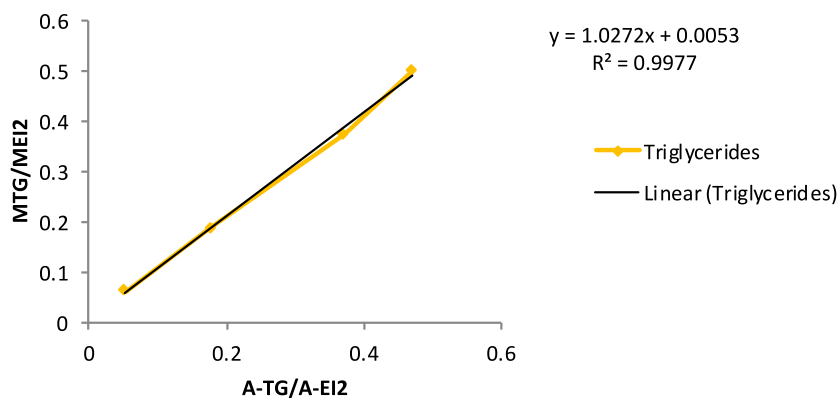
Fatty acid methyl ester (FAME) yield under conventional transesterification (CT) and ultrasonication conditions (UT); IS: internal standard; SD: standard deviation.

| CT, test 1 |                |            |                    |            |           |
|------------|----------------|------------|--------------------|------------|-----------|
| Time (s)   | IS weight (mg) | IS area    | Sample weight (mg) | Sum area   | Yield (%) |
| 30         | 49.685         | 131,795.50 | 305.56             | 732,246.72 | 74.08     |
| 60         | 49.685         | 131,559.48 | 233.07             | 653,112.66 | 84.51     |
| 120        | 50.389         | 94,232.13  | 242.50             | 494,636.43 | 88.29     |
| 300        | 50.389         | 93,198.96  | 233.20             | 474,155.35 | 88.32     |
| 600        | 50.394         | 137,183.22 | 236.89             | 712,625.21 | 89.23     |
| 1200       | 49.685         | 91,297.18  | 243.00             | 499,055.05 | 91.32     |
| 1500       | 49.685         | 91,297.18  | 242.30             | 499,055.05 | 91.58     |
| 1800       | 50.389         | 95,049.29  | 244.20             | 518,259.41 | 91.88     |
| 2400       | 50.289         | 91,297.18  | 242.30             | 499,055.05 | 92.70     |
| 3600       | 50.289         | 92,646.79  | 233.50             | 497,752.07 | 94.17     |
| CT, test 2 |                |            |                    |            |           |
| Time (s)   | IS weight (mg) | IS area    | Sample weight (mg) | Sum area   | Yield (%) |
| 30         | 49.685         | 131,795.50 | 305.69             | 732,246.72 | 74.05     |
| 60         | 49.685         | 131,559.48 | 233.10             | 653,112.66 | 84.50     |
| 120        | 50.389         | 94,232.13  | 242.60             | 494,636.43 | 88.26     |
| 300        | 50.389         | 95,049.43  | 243.00             | 501,924.73 | 88.76     |
| 600        | 50.394         | 137,183.22 | 236.94             | 712,625.21 | 89.22     |
| 1200       | 49.685         | 91,297.18  | 243.10             | 499,055.05 | 91.28     |
| 1500       | 49.685         | 91,297.18  | 242.15             | 499,055.05 | 91.64     |
| 2400       | 50.389         | 95,049.29  | 244.20             | 518,259.41 | 91.87     |
| 1800       | 50.289         | 91,297.18  | 242.30             | 499,055.05 | 92.70     |
| 3600       | 50.289         | 92,646.79  | 233.45             | 497,752.07 | 94.19     |
| UT, test 1 |                |            |                    |            |           |
| Time (s)   | IS weight (mg) | IS area    | Sample weight (mg) | Sum area   | Yield (%) |
| 5          | 50.389         | 131,795.50 | 305.69             | 801,246.72 | 83.73     |
| 10         | 50.389         | 131,559.48 | 222.70             | 620,012.66 | 84.01     |
| 30         | 50.389         | 97,932.13  | 241.20             | 494,636.43 | 84.63     |
| 60         | 50.389         | 96,932.13  | 241.20             | 494,636.43 | 85.71     |
| 120        | 50.389         | 96,547.70  | 221.00             | 466,988.05 | 87.48     |
| 300        | 50.389         | 91,015.18  | 254.80             | 499,055.05 | 88.66     |
| 600        | 49.685         | 91,097.18  | 249.30             | 499,055.05 | 89.25     |
| 1200       | 50.389         | 95,030.29  | 242.02             | 518,259.41 | 92.73     |
| 1500       | 50.289         | 91,297.18  | 242.40             | 499,055.05 | 92.66     |
| 1800       | 50.289         | 91,490.79  | 241.00             | 497,752.07 | 92.66     |
| 2400       | 49.685         | 91,490.79  | 238.00             | 497,752.07 | 92.70     |
| 3600       | 50.289         | 91,297.18  | 242.40             | 499,055.05 | 92.66     |
| UT, test 2 |                |            |                    |            |           |
| Time (s)   | IS weight (mg) | IS area    | Sample weight (mg) | Sum area   | Yield (%) |
| 5          | 50.389         | 133,795.50 | 300.90             | 801,246.72 | 83.54     |
| 10         | 50.389         | 130,959.48 | 223.90             | 620,012.66 | 84.04     |
| 30         | 50.389         | 97,932.13  | 241.20             | 494,636.43 | 84.63     |
| 60         | 50.389         | 96,932.13  | 241.20             | 494,636.43 | 85.71     |
| 120        | 50.389         | 96,647.70  | 220.30             | 466,988.05 | 87.65     |
| 300        | 50.389         | 91,015.18  | 254.80             | 499,055.05 | 88.66     |
| 600        | 50.389         | 91,097.18  | 249.30             | 499,055.05 | 90.52     |
| 1200       | 50.389         | 94,930.29  | 242.02             | 518,259.41 | 92.84     |
| 1500       | 50.389         | 91,297.18  | 243.40             | 499,055.05 | 92.46     |
| 1800       | 50.389         | 91,570.79  | 240.00             | 497,752.07 | 92.84     |
| 2400       | 50.389         | 91,297.18  | 242.40             | 499,055.05 | 93.13     |
| 3600       | 50.389         | 91,284.79  | 239.00             | 497,752.07 | 93.88     |

(continued on next page)

(continued)

| Conventional transesterification (CT) (average between tests 1 & 2)        |                  |        |         |      |
|--|------------------|--------|---------|------|
| Time s   | Test 1 Yield (%) | Test 2 | Average | SD   |
| 30   | 74.08            | 74.05  | 74.07   | 0.02 |
| 60   | 84.51            | 84.50  | 84.51   | 0.01 |
| 120  | 88.29            | 88.26  | 88.28   | 0.03 |
| 300  | 88.32            | 88.76  | 88.54   | 0.31 |
| 600  | 89.23            | 89.22  | 89.23   | 0.01 |
| 1200   | 91.32            | 91.28  | 91.30   | 0.03 |
| 1500   | 91.58            | 91.64  | 91.61   | 0.04 |
| 1800   | 91.88            | 91.87  | 91.87   | 0.01 |
| 2400   | 92.70            | 92.66  | 92.68   | 0.03 |
| 3600   | 94.17            | 94.19  | 94.18   | 0.01 |
| Ultrasound assisted-transesterification (UT) (average between tests 1 & 2) |                  |        |         |      |
| Time s   | Test 1 Yield (%) | Test 2 | Average | SD   |
| 5  | 83.73            | 83.54  | 83.64   | 0.13 |
| 10   | 84.01            | 84.04  | 84.03   | 0.03 |
| 30   | 84.63            | 84.63  | 84.63   | 0.00 |
| 60   | 85.71            | 85.71  | 85.71   | 0.00 |
| 120  | 87.48            | 87.65  | 87.57   | 0.12 |
| 300  | 88.66            | 88.66  | 88.66   | 0.00 |
| 600  | 89.25            | 90.52  | 89.89   | 0.90 |
| 1200   | 92.73            | 92.84  | 92.79   | 0.08 |
| 1500   | 92.66            | 92.46  | 92.56   | 0.14 |
| 1800   | 92.66            | 92.84  | 92.75   | 0.13 |
| 2400   | 92.70            | 93.13  | 92.91   | 0.30 |
| 3600   | 93.20            | 93.88  | 93.54   | 0.48 |



**Fig. 3.** Triglyceride content calibration curve. MTG: triglyceride concentration; MEI2: internal standard concentration; A-TG: triglyceride area; A-EI2: internal standard area.

together, homogenized, lyophilized and stored at 4 °C, oil was extracted using Soxhlet method. Lipids were winterized under centrifugation at 2000 rpm, during 10 min, at 0 °C, as explained in [1]. For each analysis, three replicates were considered (samples 1–3), while four points were used to design each calibration curve. Oil was characterized as previously mentioned. Principal component analysis was used to classify the lipids considering most frequently used oils to provide biodiesel through transesterification. Acid value was measured to check whether a pre-treatment consisting in an acid esterification, prior to transesterification, was needed. Ex-

**Table 5**

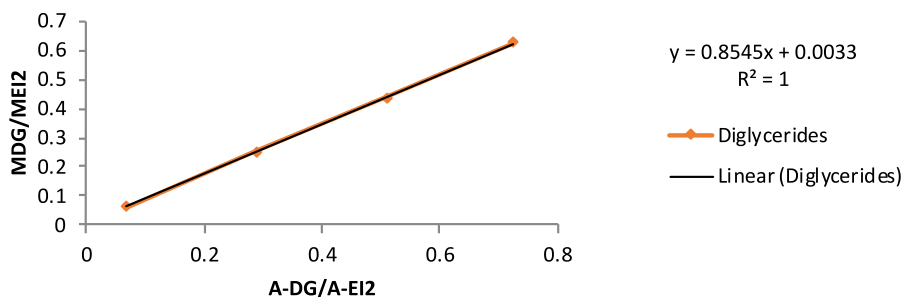
Glyceride concentration vs. time during ultrasound assisted transesterification. Dly: glycerides, TG: triglycerides, DG: diglycerides, MG: monoglycerides.

| Time (s) | sample (mg) | EI1 (mg) | EI2 (mg) | EI1 (surface) | EI2 (surface) | Gly (surface) | MG (surface) | DG (surface) | TG (surface) | Gly (%) | MG (%) | DG (%) | TG (%) |
|----------|-------------|----------|----------|---------------|---------------|---------------|--------------|--------------|--------------|---------|--------|--------|--------|
| 0        |             |          |          |               |               |               |              |              |              |         | 0.00   | 0.00   | 100.00 |
| 5        | 44.90       | 0.07     | 0.40     | 11,217.00     | 32,661.00     | 1522.00       | 86,288.00    | 33,293.00    | 72,415.80    | 0.56    | 1.79   | 0.78   | 2.63   |
| 10       | 46.80       | 0.07     | 0.40     | 9337.00       | 27,647.00     | 2235.00       | 54,503.00    | 20,671.00    | 39,325.00    | 0.83    | 1.30   | 0.55   | 1.27   |
| 30       | 53.90       | 0.07     | 0.40     | 10,538.00     | 34,745.00     | 2218.00       | 56,467.00    | 22,492.00    | 43,787.00    | 0.65    | 0.93   | 0.42   | 0.98   |
| 60       | 52.00       | 0.07     | 0.40     | 10,662.00     | 33,406.00     | 1422.00       | 48,474.00    | 20,940.00    | 41,353.00    | 0.48    | 0.86   | 0.42   | 0.99   |
| 120      | 53.10       | 0.07     | 0.40     | 11,547.00     | 33,760.00     | 391.00        | 40,239.00    | 12,299.00    | 39,575.00    | 0.22    | 0.69   | 0.24   | 0.92   |
| 300      | 53.11       | 0.07     | 0.40     | 12,159.00     | 29,074.00     | 2104.00       | 30,171.00    | 6409.00      | 26,646.00    | 0.57    | 0.60   | 0.15   | 0.72   |
| 600      | 55.17       | 0.07     | 0.40     | 11,717.00     | 33,258.00     | 783.00        | 34,630.00    | 3649.00      | 28,996.00    | 0.29    | 0.58   | 0.07   | 0.66   |
| 1800     | 53.69       | 0.07     | 0.40     | 11,670.00     | 32,624.00     | 374.00        | 24,500.00    | 3978.00      | 28,229.00    | 0.21    | 0.43   | 0.08   | 0.67   |

**Table 6**  
Calibration curve data.

|            | EI1 ( $\mu\text{g}$ ) | EI2       | GLY         | MG         | DG          | TG         | MGLY/MEI1  | MMG/MEI2   | MDG/MEI2  | MTG/MEI2 | A-gly   | A-EI1   | A-MG      |
|------------|-----------------------|-----------|-------------|------------|-------------|------------|------------|------------|-----------|----------|---------|---------|-----------|
| Solution 1 | 80                    | 800       | 5.1         | 101.8      | 49.0        | 49.9       | 1.27       | 0.13       | 0.06      | 0.06     | 975.72  | 7891.96 | 9209.15   |
| Solution 2 | 80                    | 800       | 15.4        | 254.4      | 98.0        | 99.9       | 3.18       | 0.32       | 0.12      | 0.12     | 2160.83 | 8437.27 | 16,940.57 |
| Solution 3 | 80                    | 800       | 25.7        | 508.8      | 196.0       | 199.7      | 6.36       | 0.64       | 0.25      | 0.25     | 3309.88 | 7707.42 | 37,217.30 |
| Solution 4 | 80                    | 800       | 51.3        | 1018       | 490.1       | 499.3      | 12.72      | 1.27       | 0.61      | 0.62     | 6271.17 | 8430.81 | 73,333.05 |
|            | A-EI2                 | A-DG      |             | A-TG       | A-GLY/A-EI1 | A-MG/A-EI2 | A-DG/A-EI2 | A-TG/A-EI2 | MGLY/MEI1 | MMG/MEI2 |         |         |           |
| Solution 1 | 38,075.73             | 2218.31   | 1799.46     | 1485.39    | 0.12        | 0.24       | 0.06       | 0.04       | 3.13      | 0.31     |         |         |           |
| Solution 2 | 39,582.00             | 5405.35   | 6019.57     | 3626.52    | 0.26        | 0.43       | 0.14       | 0.09       | 7.51      | 0.75     |         |         |           |
| Solution 3 | 43,923.84             | 11,869.14 |             | 10,731.97  | 0.43        | 0.85       | 0.27       | 0.24       | 11.88     | 1.19     |         |         |           |
| Solution 4 | 23,846.00             | 31,824.57 |             | 20,508.81  | 0.74        | 3.08       | 1.33       | 0.86       | 15.63     | 1.56     |         |         |           |
|            | MDG/MEI2              | MTG/MEI2  | A-GLY/A-EI1 | A-MG/A-EI2 | A-DG/A-EI2  | A-TG/A-EI2 |            |            |           |          |         |         |           |
| Solution 1 | 0.063                 | 0.063     | 0.105       | 0.400      | 0.069       | 0.052      |            |            |           |          |         |         |           |
| Solution 2 | 0.250                 | 0.188     | 0.324       | 0.982      | 0.288       | 0.178      |            |            |           |          |         |         |           |
| Solution 3 | 0.438                 | 0.375     | 0.516       | 1.565      | 0.511       | 0.372      |            |            |           |          |         |         |           |
| Solution 4 | 0.624                 | 0.501     | 0.735       | 2.036      | 0.725       | 0.473      |            |            |           |          |         |         |           |





**Fig. 4.** Diglyceride content calibration curve. MDG: diglyceride concentration; MEI2: internal standard concentration; A-MG: triglyceride area; A-AEI2: internal standard area.

**Table 7**

Energy use index (EUI) to compare conventional and ultrasound-assisted transesterification; SD: standard deviation.

| Parameters   | Esterification+<br>conventional<br>transesterification | Esterification + ultrasound-<br>assisted<br>transesterification |
|--|--|---|
| <b>FIRST STEP: ESTERIFICATION</b>  |  |   |
| Low calorific vale (J/g)   | 37,032.24  | 37,032.24   |
| Amount of consumed energy, previous esterification (J/g)                 | 31,500   | 31,500  |
| Mass unit sample 1 (g)   | 12.11  | 12.11   |
| Mass unit sample 2 (g)   | 11.43  | 11.43   |
| Mass unit sample 3 (g)   | 11.70  | 11.70   |
| EUI 1  | 14.24  | 14.24   |
| EUI 2  | 13.44  | 13.44   |
| EUI 3  | 13.75  | 13.75   |
| EUI average  | 13.81  | 13.81   |
| SD   | 0.40   | 0.40  |
| <b>SECOND STEP: TRANSESTERIFICATION</b>                                  |  |   |
| Low calorific vale (J/g)   | 37,032.24  | 37,032.24   |
| Amount of consumed energy during transesterification 1 (J/g)             | 378,000  | 90,398  |
| Amount of consumed energy during transesterification, repetition 2 (J/g) | n.d.   | 81,968  |
| Amount of consumed energy during transesterification, repetition 3 (J/g) | n.d.   | 91,413  |
| Mass unit sample 1 (g)   | 12.11  | 14.06   |
| Mass unit sample 2 (g)   | 11.43  | 12.60   |
| Mass unit sample 3 (g)   | 11.7   | 13.82   |
| EUI 1  | 1.19   | 5.76  |
| EUI 2  | 1.12   | 5.69  |
| EUI 3  | 1.15   | 5.60  |
| EUI average  | 1.15   | 5.68  |
| SD   | 0.03   | 0.05  |
| Consumed energy (EUI)  | Average  | SD  |
| EUI previous esterification  | 13.81  | 0.33  |
| EUI conventional transesterification                                     | 1.15   | 0.03  |
| EUI ultrasound Transesterification                                       | 5.68   | 0.07  |

perimental design was performed with Statgraphics Centurion XVI software and Box-Behnken design [1].

Ultrasound-assisted transesterification was carried out with a sonicator probe Q700 QSonica LLC, under a frequency of 20 kHz, 100% duty cycle and 50% amplitude. The consumption of energy was analyzed using Eq. (1) and two Fluke power analyzers working at 1000 V rms and

**Table 8**  
Quality analysis of biodiesel from solid food waste oil following European standard EN 14214; CFPP: cold filter plugging point; Gly: glycerides; MD: monoglycerides; DG: diglycerides; TG: triglycerides; SD: standard deviation.

| Quality parameters   | EN 14214                 | Experimental data from conventional transesterification      |           |           |           |          |           |           |           |         |        |        |        |
|--|--------------------------|--|-----------|-----------|-----------|----------|-----------|-----------|-----------|---------|--------|--------|--------|
|  | Method and threshold     | sample 1   | Sample 2  | Sample 3  | Average   | SD       |           |           |           |         |        |        |        |
| Water content (mg/g)   | EN ISO 12937; Max: 500   | 281.46   | 271.50    | 194.06    | 249.00    | 47.85    |           |           |           |         |        |        |        |
| Kinematic viscosity at 40 °C (mm <sup>2</sup> /s)  | EN ISO 3104; 3.5–5.0     | 4.03   | 4.10      | 4.17      | 4.10      | 0.07     |           |           |           |         |        |        |        |
| Density at 15 °C (g/L)   | EN ISO 3675; 860–900     | 870  | 871       | 869       | 870       | 1        |           |           |           |         |        |        |        |
| CFPP ( °C)   | EN 116                   | −4.0   | −4.0      | −4.0      | −4.0      | 0.0      |           |           |           |         |        |        |        |
| Low calorific value (J/g)  | ASTM D240; Min: 35,000   | 39,339.00  | 39,530.00 | 39,493.00 | 39,454.00 | 103.18   |           |           |           |         |        |        |        |
| Oxidation stability (h)  | EN 14112; Min: 8         | 2.16   | 2.10      | 2.05      | 2.10      | 0.06     |           |           |           |         |        |        |        |
| Flash point ( °C)  | EN ISO 3679; Min: 101    | 165  | 167       | 166       | 166       | 1        |           |           |           |         |        |        |        |
| Carbon residue (% w/w)   | EN ISO 10,370; Max: 0.30 | 0.045  | 0.013     | 0.020     | 0.026     | 0.02     |           |           |           |         |        |        |        |
| Acid value (mg KOH/g)  | EN 14104; Max: 0.50      | 0.150  | 0.170     | 0.160     | 0.160     | 0.010    |           |           |           |         |        |        |        |
| Quantitative analysis by inductivity coupled plasma mass spectrometry (ICP-MS) Conventional transesterification        |                          |  |           |           |           |          |           |           |           |         |        |        |        |
|  | Sample 1                 | Sample 2   | Average   |           | SD        |          |           |           |           |         |        |        |        |
| Na (ppm)   | 5.015                    | 5.192  | 5.100     |           | 0.130     |          |           |           |           |         |        |        |        |
| K (ppm)  | 0.653                    | 0.730  | 0.690     |           | 0.050     |          |           |           |           |         |        |        |        |
| Mg (ppm)   | 0.099                    | 0.064  | 0.082     |           | 0.024     |          |           |           |           |         |        |        |        |
| Cu (ppb)   | 1233.224                 | 1196.420   | 1214.000  |           | 26.710    |          |           |           |           |         |        |        |        |
| Quality parameters   | EN 14214                 | Experimental data of ultrasound-assisted transesterification |           |           |           |          |           |           |           |         |        |        |        |
|  | Method and threshold     | sample 1   | Sample 2  | Sample 3  | Average   | SD       |           |           |           |         |        |        |        |
| Water content (mg/g)   | EN ISO 12937; Max: 500   | 280.60   | 472.25    | 387.16    | 380.00    | 96.02    |           |           |           |         |        |        |        |
| Kinematic viscosity at 40 °C (mm <sup>2</sup> /s)  | EN ISO 3104; 3.5–5.0     | 4.17   | 4.20      | 4.31      | 4.23      | 0.07     |           |           |           |         |        |        |        |
| Density at 15 °C (g/L)   | EN ISO 3675; 860–900     | 880  | 880       | 880       | 880       | 1        |           |           |           |         |        |        |        |
| CFPP ( °C)   | EN 116                   | −4.0   | −3.0      | −4.0      | −3.7      | 0.6      |           |           |           |         |        |        |        |
| Low calorific value (J/g)  | ASTM D240; Min: 35,000   | 39,625.0   | 39,585.0  | 39,506.0  | 39,572.0  | 60.6     |           |           |           |         |        |        |        |
| Oxidation stability (h)  | EN 14112; Min: 8         | 3.18   | 3.22      | 3.35      | 3.25      | 0.08     |           |           |           |         |        |        |        |
| Flash point ( °C)  | EN ISO 3679; Min: 101    | 160  | 165       | 164       | 163       | 3        |           |           |           |         |        |        |        |
| Carbon residue (% w/w)   | EN ISO 10370; Max: 0.30  | 0.0458   | 0.0120    | 0.0205    | 0.0261    | 0.0176   |           |           |           |         |        |        |        |
| Acid value (mg KOH/g)  | EN 14104; Max: 0.50      | 0.17   | 0.16      | 0.17      | 0.17      | 0.01     |           |           |           |         |        |        |        |
| Quantitative analysis by inductivity coupled plasma mass spectrometry (ICP-MS) Ultrasound-assisted transesterification |                          |  |           |           |           |          |           |           |           |         |        |        |        |
|  | Sample 1                 | Sample 2   | Average   |           | SD        |          |           |           |           |         |        |        |        |
| Na (ppm)   | 5.254                    | 5.147  | 5.200     |           | 0.080     |          |           |           |           |         |        |        |        |
| K (ppm)  | 0.63                     | 0.71   | 0.67      |           | 0.05      |          |           |           |           |         |        |        |        |
| Mg (ppm)   | 0.092                    | 0.071  | 0.081     |           | 0.015     |          |           |           |           |         |        |        |        |
| Cu (ppb)   | 1223.00                  | 1187.00  | 1205.00   |           | 25.45     |          |           |           |           |         |        |        |        |
| sample   | sample (mg)              | EI1 (mg)   | EI2 (mg)  | Area EI1  | Area EI2  | Area Gly | Area MG   | Area DG   | Area TG   | Gly (%) | MG (%) | DG (%) | TG (%) |
| <b>Conventional transesterification</b>  | 54.98                    | 0.07   | 0.40      | 11,208.00 | 28,116.00 | 3272.00  | 38,877.00 | 16,284.00 | 26,547.00 | 0.83    | 0.78   | 0.37   | 0.72   |
| <b>Ultrasound-assisted transesterification</b>   | 54.30                    | 0.07   | 0.40      | 11,901.00 | 29,821.00 | 2934.00  | 22,933.00 | 9984.00   | 23,263.00 | 0.73    | 0.44   | 0.22   | 0.60   |

**Table 9**

Detailed quantitative analysis of metal content by inductivity coupled plasma mass spectrometry (ICP-MS). Initial sample quantity (mg): 507.9; sample preparation volume (mL): 10.0; aliquot volume (mL): 1.0; diluted to volume (mL): 10.0.

| Element | Mass (ppb)      | Intensity |
|---------|-----------------|-----------|
| H       | –               | –         |
| He      | –               | –         |
| Li      | 0.000           | 0         |
| Be      | 5.587           | 10        |
| B       | 86.939          | 65        |
| C       | 0.000           | 0         |
| N       | 145,333,219.428 | 131,014   |
| O       | –               | –         |
| F       | –               | 6454      |
| Ne      | 0.000           | 0         |
| Na      | 3774.583        | 26,439    |
| Mg      | 0.000           | 0         |
| Al      | 0.000           | 0         |
| Si      | 0.000           | 0         |
| P       | 0.000           | 0         |
| S       | 8553.083        | 2875      |
| Cs      | 0.000           | 0         |
| Ar      | 0.000           | 0         |
| K       | 0.000           | 0         |
| Ca      | 0.000           | 0         |
| Sc      | 0.000           | 0         |
| Ti      | 0.000           | 0         |
| V       | 0.000           | 0         |
| Cr      | 0.000           | 0         |
| Mn      | 0.000           | 0         |
| Fe      | 0.000           | 0         |
| Co      | 0.000           | 0         |
| Ni      | 0.000           | 0         |
| Cu      | 1181.982        | 81,545    |
| Zn      | 1520.834        | 25,832    |
| Ga      | 0.000           | 0         |
| Ge      | 0.000           | 0         |
| As      | 0.000           | 0         |
| Se      | 0.000           | 0         |
| Br      | 103.552         | 63        |
| Kr      | 0.000           | 0         |
| Rb      | 0.000           | 0         |
| Sr      | 0.000           | 0         |
| Y       | 0.000           | 0         |
| Zr      | 0.000           | 0         |
| Nb      | 0.000           | 0         |
| Mo      | 0.000           | 0         |
| Ru      | 0.000           | 0         |
| Rh      | 0.000           | 0         |
| Pd      | 0.000           | 0         |
| Ag      | 0.000           | 0         |
| Cd      | 0.000           | 0         |
| In      | 0.000           | 0         |
| Sn      | 0.000           | 0         |
| Te      | 0.000           | 0         |
| I       | 278.157         | 1591      |
| Xe      | 0.000           | 0         |
| Cs      | 0.000           | 0         |
| Ba      | 0.000           | 0         |
| La      | 0.130           | 17        |
| Ce      | 0.000           | 0         |

(continued on next page)

**Table 9** (continued)

| Element | Mass (ppb) | Intensity |
|---------|------------|-----------|
| Pr      | 0.000      | 0         |
| Nd      | 0.000      | 0         |
| Sm      | 0.000      | 0         |
| Eu      | 0.057      | 10        |
| Gd      | 0.000      | 0         |
| Tb      | 0.346      | 74        |
| Dy      | 0.000      | 0         |
| Ho      | 0.337      | 76        |
| Er      | 0.304      | 69        |
| Tm      | 0.137      | 34        |
| Yb      | 0.000      | 0         |
| Lu      | 0.196      | 35        |
| Hf      | 0.000      | 0         |
| Ta      | 0.000      | 0         |
| W       | 0.000      | 0         |
| Re      | 0.000      | 0         |
| Os      | 0.000      | 0         |
| Ir      | 0.000      | 0         |
| Pt      | 0.164      | 17        |
| Au      | 0.000      | 0         |
| Hg      | 0.000      | 0         |
| Tl      | 0.311      | 65        |
| Pb      | 63.352     | 12,939    |
| Bi      | 0.449      | 71        |
| Th      | 0.000      | 0         |
| U       | 0.000      | 0         |

1250 V rms, respectively. More details are provided in reference [1]. Biodiesel characterization was carried out following European biodiesel standard EN 14,214. Metal content was analyzed using by ICP-MS.

### Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships which have, or could be perceived to have, influenced the work reported in this article.

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### Supplementary materials

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