Research Article

Standardization of vegetable oils composition to be used as oleochemistry feedstock through a selective hydrogenation process

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Selective hydrogenation over pre-reduced 8% Cu/SiO₂ catalysts has been carried out on a series of non-food oils methylesters. The catalyst shows a very high diene:monoene selectivity, thus allowing one to reduce not only the linolenic component, but also the linoleic one in this way enriching the oil in oleic acid and avoiding a contemporary increase in stearic acid concentration. This treatment improves the oxidation stability of the oil while keeping acceptable viscosity and cold properties and can be used to standardize a wide variety of different available feedstock.

Practical applications: Vegetable oils from different sources can be used as primary, secondary (when they are residues of other processes), or tertiary (post-consumer wastes) feedstock for the chemical industry. Their composition can be very different as far as unsaturated components are concerned. This variability is an issue because it can lead to multiple products and moreover the unsaturation level, that is the iodine value, is strongly related to oxidation unstability. The process we propose here allows one to standardize the oil composition improving the oxidation stability and keeping acceptable fluidity. The very mild experimental conditions, 4–6 atm of H₂ and 160–180°C, the use of a non-toxic and cheap metal, make this process sustainable and easily viable, e.g., in hardening plants.

Keywords: Cu catalysts / Iodine value / Oxidation stability / Selective hydrogenation

Received: May 11, 2011 / Revised: July 28, 2011 / Accepted: August 26, 2011
DOI: 10.1002/ejlt.201100044

1 Introduction

One of the fundamentals for the development of a chemical process is the reliability of the raw material both from the quality and from the economic point of view. As far as economics are concerned, vegetable oils prices have been steady or increasing with an average rate lower than the average increase rate for petrochemicals products for about 40 years. Since the end of 2007 a sky-rocketing increase particularly in food grade oils, followed by continuous fluctuations, represents a serious issue for their use as a feedstock for the chemical industry.

On the other hand, vegetable oils and animal fats are very different in fatty acids composition in terms of fatty acids chain length and number of double bonds. The main vegetable oils are constituted of a mixture of triglycerides of C16 and C18 fatty acids, but the amount of polyunsaturated components, C18:2 and C18:3 may vary depending on the nature of oil crop. The presence of C=C double bonds is necessary to introduce some functional groups, e.g., through an epoxidation reaction and to carry out different chemical transformations such as metathesis. However, the presence of several double bonds may lead to messy reactions, lower reaction rates, and worse product performance. As an example, not only cross metathesis of natural oils with butene gives several products with different geometry depending on the amount of unsaturated triglycerides in the starting material, but also only with oils containing predominantly oleic acid high turnovers were observed [1]. Mixtures derived from a natural vegetable oil containing at least 72% by weight of oleic acid were found to be suitable for the synthesis of polyol esters to be used in lubricating oils composition [2] while the quality of polyol esters to be used
for casting and coating compositions is very much improved when very high oleic, low stearic vegetable oils are used as a starting materials. In particular, 85–95% oleic acid, 2–8% linoleic, 0.5–2.5 stearic, and 2–5% palmitic was the preferred starting materials. In particular, 85–95% oleic acid, 2–8% when very high oleic, low stearic vegetable oils are used as a for casting and coating compositions is very much improved


Table 1. Influence of number, position, and geometry of double bonds on the melting point of fatty acids

<table>
<thead>
<tr>
<th>Fatty acid</th>
<th>Double bonds</th>
<th>mp [°C]</th>
</tr>
</thead>
<tbody>
<tr>
<td>9, 12, 15</td>
<td>C18:3</td>
<td>–13</td>
</tr>
<tr>
<td>9, 12</td>
<td>C18:2</td>
<td>–7</td>
</tr>
<tr>
<td>9</td>
<td>C18:1</td>
<td>+16</td>
</tr>
<tr>
<td>C18:0</td>
<td></td>
<td>+30</td>
</tr>
</tbody>
</table>

Position |
--------|
6(7)    |
9(10)   |
12(13)  |
15(16)  |

Moreover, the same Pt/ZSM-5 catalyst is also active and selective in the hydrogenation of the trans isomer of the C18:1 methylester versus the natural cis isomer [12] at 65°C and high hydrogen pressure (60 bar).

On the contrary, up to now catalysts able to improve the oxidation stability while keeping acceptable cold properties through a selective hydrogenation process are rare. Rh complexes with water soluble phosphines have been shown to be active catalysts for the hydrogenation of linseed and sunflower oil methylesters in aqueous/organic two phase systems and selective toward formation of monounsaturated components [13]. However, no tests on physical properties of the products were reported while the very high price of the catalytic system and the use of solvents suggest that this system may not be suitable for large scale applications. Heterogeneous Ni and noble metal catalysts show rather low diene:monoene selectivity, thus giving early formation of saturated compounds and the problem of achieving selective hydrogenation in unsaturated fatty acids with several double bonds without unwanted positional or cis/trans isomerization occurring at the same time has so far only been partly solved.

The use of copper hydrogenation catalysts in the fat and oils industry mainly relies on copper chromites for the production of fatty acid alcohols from esters [14]. However, copper based systems have long been known in edible oils hydrogenation as the most selective ones for the reduction of linolenate C18:3 to olate C18:1 leaving unaffected linoleate C18:2, a valuable component from the nutritional standpoint. In this case monoenes are not reduced, therefore, the percentage of saturated fatty acids is scarcely changed during the hydrogenation process [15, 16]. These catalysts are usually added into the oil mass in the oxidized form and partly reduced to Cu(I) and or Cu(0) during use while pre-reduced copper chromites have found to be strongly deactivated in soybean oil hydrogenation [17].

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Here we wish to report that low loaded Cu catalysts, prepared through the chemisorptions hydrolysis technique and pre-reduced before use to the metallic state, are effective and very selective catalysts for the hydrogenation of polyunsaturated oils allowing one to enrich very much the oil in mono-unsaturated components while keeping acceptable fluidity.

2 Materials and methods

Methylesters for hydrogenation reaction were obtained by homogeneous transesterification reaction starting from the corresponding triglycerides by using MeOH (MeOH:triglyceride = 6:1) and NaOMe or KOH as a catalyst, depending on the oil acid value. In the case of Tall Oil, methylesters were obtained by using 100 parts by weight of tall oil fatty acids (TOFA) and 100 parts by weight of methyl alcohol in the presence of 0.5 parts of concentrated sulfuric acid or 1 part of para-toluene sulphonic acid monohydrate. After drying, the ester fraction was batchwise distilled under reduced pressure (1 mbar at 180°C), in order to obtain a distilled fraction purified from rosin acids. Rosin acids are not methylated under the described experimental conditions.

The copper catalyst, with a 8% metal loading, was prepared as follows: SiO₂ (Davicat from Grace Davison, BET = 313 m²/g, PV = 1.79 mL/g) was added to a [Cu(NH₃)₄]²⁺ solution prepared by dropping aqueous ammonia to a Cu(NO₃)₂·3H₂O solution until pH 9 had been reached [18]. After 20 min under stirring, the slurry, held in an ice bath at 0°C, was diluted with water. The solid was separated by filtration, washed with water, dried over-night at 110°C, and calcinated in air in a furnace heated at 400°C. Before reaction the catalyst was pre-reduced ex situ in H₂ (1 atm) at 270°C, and transferred into the reactor under inert atmosphere.

Hydrogenation reactions were carried out in a stainless steel autoclave (Parr series 4560) at 160°C (180°C in case of Tall Oil), under pressure of 4–6 atm H₂, in presence of 2% (by weight) powdered supported Cu catalysts with a 8% copper loading. Reaction mixtures, separated by simple filtration, were analyzed by GC (HP-6890) using a non-bonded, bicyanopropylpolysiloxane (100 m) capillary column at isotherm T = 190°C. Results reported in Table 2 and Fig. 1 are the average of at least three catalytic tests (5 for rapeseed oil methylesters). Typical standard error (connected with manual injection) is ±3%.

Iodine values were evaluated by titration by using the EN 14111:2003 standard.

Control tests carried out by ICP-AES did not show any catalyst contamination in the final product.

Table 2. Selective hydrogenation of different vegetable oil methylesters over a Cu/SiO₂ catalyst (160°C, 4 atm H₂)

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Linseed oil methylesters</td>
<td>0</td>
<td>3.4 ± 0.08</td>
<td>–</td>
<td>–</td>
<td>186</td>
<td>−23</td>
<td>[19]</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>4.2 ± 0.1</td>
<td>19.8 ± 0.5</td>
<td>15 ± 0.4</td>
<td>112</td>
<td>−11</td>
<td></td>
</tr>
<tr>
<td>Plukenetia volubilis oil methylesters</td>
<td>0</td>
<td>2.7 ± 0.06</td>
<td>–</td>
<td>–</td>
<td>202</td>
<td>−25</td>
<td>[19]</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>3.0 ± 0.1</td>
<td>26 ± 0.8</td>
<td>24 ± 0.7</td>
<td>115</td>
<td>−13</td>
<td></td>
</tr>
<tr>
<td>Safflower oil methylesters</td>
<td>0</td>
<td>2.5 ± 0.1</td>
<td>–</td>
<td>–</td>
<td>140</td>
<td>−22</td>
<td></td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>2.6 ± 0.1</td>
<td>36 ± 1.1</td>
<td>4.5 ± 0.1</td>
<td>95</td>
<td>−10</td>
<td></td>
</tr>
<tr>
<td>Grapeseed oil methylesters</td>
<td>0</td>
<td>3.9 ± 0.1</td>
<td>–</td>
<td>–</td>
<td>145</td>
<td>−18</td>
<td></td>
</tr>
<tr>
<td></td>
<td>60</td>
<td>3.6 ± 0.1</td>
<td>35 ± 1.0</td>
<td>5.6 ± 0.2</td>
<td>108</td>
<td>−12</td>
<td></td>
</tr>
<tr>
<td>Pumpkin oil methylesters</td>
<td>0</td>
<td>6.7 ± 0.2</td>
<td>–</td>
<td>–</td>
<td>107</td>
<td>−8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>120</td>
<td>7.1 ± 0.2</td>
<td>26 ± 0.7</td>
<td>2 ± 0.05</td>
<td>96</td>
<td>−2</td>
<td></td>
</tr>
</tbody>
</table>

ᵃ % trans(9)C18:1/%C18:1.
ᵇ %positional/%C18:1.

Figure 1. Effect of the standardization treatment on different oils.

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Oxidation stability in Table 2 is expressed as Rancimat induction period (h/min).

### 2.1 Rancimat oxidation test

A stream of purified air is passed through the sample thermostated at a constant temperature (usually 110°C). The vapors released during the oxygenation process are transferred in a second flask containing distilled water and equipped with a conductimetric electrode. The electrode is connected to a measuring and recording device. The analytical end point (induction period) is the time when the conductivity begins to increase rapidly and it corresponds to a quick sample deterioration. The recorded conductivity increase is caused by the dissociation of volatile low MW carboxylic acids produced during the oxidation process and absorbed in the water solution.

### 3 Results and discussion

Table 2 reports the results obtained during the hydrogenation of methylesters derived from several different oils over pre-reduced 8% Cu/SiO2 under very mild experimental conditions. We already reported on the hydrogenation of several oils high in C18:2 such as rapeseed (Brassica napus) and oils rich in C18:3 such as linseed (Linum usitatissimum) and Sacha Inchi (Plukenetia Volubilis) oil [19]. In this paper we add results obtained with an oil containing approx. 50% of dienic components like pumpkin (Cucurbita spp) seed oil and another oil rich in linoleic acid such as safflower oil (Carthamus tinctorius). Notwithstanding the very different initial composition of these oils, all of them can be easily reduced to produce methylesters with fairly high monounsaturated ester content (Fig. 1). The effect of the treatment on oxidative stability was measured for linseed oil. The Rancimat oxidation stability rose from a very low 1.2 to 5.3 h, thus showing the effect of removing polyunsaturated components.

On the other hand, the stearic acid content keeps nearly unchanged during the hydrogenation process and cis/trans and positional isomerization are limited. In particular, the trans content varied from 20 to 36% under these experimental conditions and it is higher for the oils with very high content in C18:2. On the contrary, the amount of positional isomers, mostly Δ12 C18:1, is higher for oils derived from high linolenic starting materials, in agreement with the hydrogenation mechanism proposed (vide infra). On the other oils the amount of positional isomers is very low.

The selectivity of the copper based system toward formation of the monoenic component without increasing of the saturated one and with limited isomerization allows the oil to maintain good cold properties, in this case represented by the pour point, the analogous of melting point for mixtures.

A significant improvement in oxidative stability was recorded also with Tall Oil Methylesters, which are very unstable before treatment because of the presence of conjugated dienes (Table 3).

Table 3 sums up results obtained in the hydrogenation of tall Oil methylesters under mild experimental conditions [20]. The reaction was very fast and led to nearly complete suppression of conjugated dienes and significant reduction of linoleic acid derivative leaving unaffected the stearic acid content. Owing to this very high selectivity, not only the IV can be reduced to meet the European standard for biodiesel (EN 14214 requires IVmax = 120) but also excellent cold properties can be obtained, the hydrogenated oil is completely colorless and moreover the treatment improves very much the Conradson carbon residue, that is to say the tendency for fuels to form carbon deposits when used with stoichiometric quantities of combust, such as for example in diesel cycle engines.

Iodine value (IV), Conradson carbon residue (CCR), and oxidation stability are three strictly co-related parameters. As a general rule the reduction of IV (on the same feedstock) dramatically improves the oxidation stability. In this case the Rancimat induction time goes from less than 1 h before the treatment to 4 h after the selective hydrogenation, showing an evident stabilization effect.

No significant differences were observed among the catalyst supported on silica and the one supported on alumina, but a low decrease in trans content was observed passing from the first to the second one and from 6 to 3 atm of H2. On the contrary a catalyst with the same Cu loading but prepared by conventional incipient wetness technique did not show any activity even after long reaction time.

A comparison test carried out over a commercial Ni catalyst shows that early formation of stearic acid (C18:0),

### Table 3. Selective hydrogenation of Tall Oil methylesters

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>Initial composition</td>
<td>44</td>
<td>11</td>
<td>37</td>
<td>0.4</td>
<td>-</td>
<td>-</td>
<td>145</td>
<td>-31</td>
</tr>
<tr>
<td>Cu/Si</td>
<td>6</td>
<td>22 ± 0.7</td>
<td>2 ± 0.05</td>
<td>68 ± 2.0</td>
<td>0.5 ± 0.1</td>
<td>28.3</td>
<td>3.4 ± 0.08</td>
<td>117</td>
</tr>
<tr>
<td>Cu/Al</td>
<td>6</td>
<td>24 ± 0.6</td>
<td>4 ± 0.1</td>
<td>63 ± 1.8</td>
<td>1 ± 0.03</td>
<td>25.2</td>
<td>2.1 ± 0.08</td>
<td>112</td>
</tr>
<tr>
<td>Ni/Si</td>
<td>4</td>
<td>25 ± 0.5</td>
<td>0.5 ± 0.02</td>
<td>56 ± 1.6</td>
<td>11 ± 0.3</td>
<td>30.2</td>
<td>4.1 ± 0.1</td>
<td>104</td>
</tr>
</tbody>
</table>

a % trans(9)C18:1/%C18:1.
b %positional/%C18:1.
when the content in C18:2 is still relatively high, and an higher content in trans isomers result in a very high pour point.

Tall oil is a particularly interesting starting material. The peculiarity of this material is that it consists of a mixture of acids and not triglycerides; therefore its transformation in Biodiesel or in other esters requires only an esterification reaction instead of a trans-esterification one and therefore does not produce glycerol, making the total economy lighter and independent of the critical marketing of this polyalcohol. Moreover, it is a secondary raw material. Thus, it is a by-product of sulfate cooking (Kraft cooking) of cellulose and it is obtained by distilling acid splitted soaps, the soap being created when resinic and fatty acids are saponified during the Kraft process.

Its use as raw material for the synthesis of biodegradable hydraulic oils, namely esters of neopentyl glycol, trimethylolpropane and pentaerythrol, has already been proposed [21]. These esters show good water separation properties and are therefore very useful as hydraulic oil application, which often involves the problem of water becoming dispersed in the oil, but they require the addition of significant amounts of oxidation inhibitors due to the low oxidation stability of the parent oil.

Figure 1 puts in evidence how this treatment allows one to start with materials having IV ranging from 107 to 202 to obtain a series of oils having a narrower IV range (95–117) and more homogeneous composition as far as C18:2 and C18:1 are concerned. This is particularly evident if we compare linseed oil with tall oil: these two materials have very different starting composition besides very different IV, but after the treatment they end up in oils with very similar composition.

In the particular case of rapeseed oil methylesters (Table 4) where the starting material already contains a significant amount of oleic acid derivative, it is possible to obtain up to 88% of C18:1 derivative without modifying the amount of C18:0 and with a trans-content of about 20%. The reaction can be carried out at 20 or 6 bar of H2 pressure without significant differences neither in selectivity nor in reaction rate, but a lower amount of trans isomers when working under lower pressure was observed. No significant differences were observed under the experimental conditions used, among several kind of silica tested. Thus, silica gels with different surface areas and porosity as well as pyrogenic silica can be used.

A support less acidic than silica, such as alumina gave a less active but still very selective catalyst. Acidic materials such as SiO2–TiO2 and SiO2–Al2O3, that were found to be active in the esterification reaction of free fatty acids present in crude oils [23] were also tested as catalyst supports.

The use of the materials obtained in this way put in evidence the influence of stearic acid and trans isomers formation on the cold properties. Thus, the catalyst supported on SiO2–TiO2 (entry 5) produced a small increase in C18:0, from 2 to 5% that in turn brought an increase in the pour point to −4°C. On the other hand, the Cu/SiAl catalyst (entry 6) was a little bit less active and produced a higher amount of trans isomers, thus bringing the pour point to −9°C.

The effect of the preparation method and of the reduction pre-treatment is crucial.

The very high diene:monoene selectivity shown by the Cu catalysts here described, is due to the catalyst preparation method [18]: a catalyst having the same composition, but prepared by the conventional incipient wetness (IW) technique (entry 7) did not show any activity under the same experimental conditions. On the other hand, the use of the unreduced Cu/silica catalyst (entry 8) in the reduction of rapeseed oil methylesters resulted in the slow reduction of C18:3 to C18:1 leaving the C18:2 concentration unaffected, in agreement with results reported by Johansson and Koritala [15, 24].

Table 4. Hydrogenation of rapeseed oil methylesters in the presence of different Cu catalysts at 180°C

<table>
<thead>
<tr>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Composition</td>
<td></td>
<td></td>
<td></td>
<td>11</td>
<td>21</td>
<td>59</td>
<td>2</td>
<td>0</td>
<td>-25</td>
</tr>
<tr>
<td>1</td>
<td>Cu/Si</td>
<td>20</td>
<td>1</td>
<td>0</td>
<td>8 ± 0.2</td>
<td>83 ± 2.4</td>
<td>2 ± 0.04</td>
<td>15 ± 0.4</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Cu/Si</td>
<td>3</td>
<td>0</td>
<td>3 ± 0.08</td>
<td>88 ± 2.5</td>
<td>2 ± 0.06</td>
<td>20 ± 0.5</td>
<td>-15</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Cu/Si</td>
<td>6</td>
<td>1</td>
<td>0</td>
<td>13 ± 0.3</td>
<td>78 ± 2.2</td>
<td>2 ± 0.04</td>
<td>12 ± 0.3</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Cu/Si</td>
<td>3</td>
<td>0</td>
<td>4 ± 0.1</td>
<td>87 ± 2.5</td>
<td>2 ± 0.05</td>
<td>17 ± 0.5</td>
<td>-13</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Cu/Si/Ti</td>
<td>20</td>
<td>3</td>
<td>0</td>
<td>4 ± 0.08</td>
<td>84 ± 2.1</td>
<td>5 ± 0.1</td>
<td>21 ± 0.6</td>
<td>-4</td>
</tr>
<tr>
<td>6</td>
<td>Cu/SiAl</td>
<td>20</td>
<td>3</td>
<td>2 ± 0.06</td>
<td>8 ± 0.2</td>
<td>81 ± 1.6</td>
<td>2 ± 0.06</td>
<td>32 ± 0.8</td>
<td>-9</td>
</tr>
<tr>
<td>7</td>
<td>Cu/Al</td>
<td>20</td>
<td>0</td>
<td>6</td>
<td>6 ± 0.2</td>
<td>85 ± 2.2</td>
<td>2 ± 0.05</td>
<td>14 ± 0.4</td>
<td>-15</td>
</tr>
<tr>
<td>8</td>
<td>Cu/Al/T</td>
<td>20</td>
<td>22</td>
<td>8 ± 0.2</td>
<td>24 ± 0.6</td>
<td>59 ± 1.6</td>
<td>2 ± 0.06</td>
<td>-15</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>CuO/Si</td>
<td>20</td>
<td>20</td>
<td>1 ± 0.05</td>
<td>23 ± 0.6</td>
<td>67 ± 2.0</td>
<td>2 ± 0.06</td>
<td>-9</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Ni/Si</td>
<td>4</td>
<td>1</td>
<td>0</td>
<td>4 ± 0.08</td>
<td>78 ± 1.9</td>
<td>11 ± 0.3</td>
<td>30 ± 0.9</td>
<td>+7</td>
</tr>
</tbody>
</table>

a % trans(9)C18:1/%C18:1.
This shows the relevance of the reduction pre-treatment on the very high catalyst activity and diene:monoene selectivity. Thus, reduction of the catalyst ex situ, that is in the absence of the oil, allows one to remove all the water formed during the reduction process, according to the reaction scheme:

\[
\text{CuO} + \text{H}_2 \rightarrow \text{Cu} + \text{H}_2\text{O}
\]

When the catalyst is reduced in situ, as it is generally done with copper chromites, the water formed and trapped inside the catalyst pores reduces its activity generating a system with high selectivity toward hydrogenation of C18:3, whereas reduction of the precursor CuO in the absence of the substrate allows one to obtain a catalyst that is still inactive towards C18:1 hydrogenation, but very active towards both C18:2 and C18:3 unsaturated systems. The relevance of pre-reduction treatments in preserving the activity of chromium free copper catalysts has already been recognized [25].

Pre-reduction of these materials to catalysts exposing high metallic surface area allows one to hydrogenate under mild conditions the dienic components too, without reducing C18:1 and thus producing oils having a high oleic acid content (but without rising the stearic acid concentration). According to the mechanism proposed by Dijkstra [26] this may be due to the higher activity of reduced Cu in hydrogen abstraction, as also shown in dehydrogenation reactions [27]. Thus, the hydrogenation of polyunsaturated oils proceeds through conjugation of the methylene interrupted double bonds that is in turn caused by hydrogen abstraction. The faster hydrogenation observed for oils with high linolenic content (Linseed and Sacha Inchi oil methylesters) with respect to the ones with high linoleic content and the presence of almost only the \(1,2\) positional isomer in the hydrogenation product of these oils also support the hypothesis of the hydrogen abstraction. Actually, the twice activated allylic hydrogens of a methylene group separating two double bonds have a higher probability of being abstracted than allylic hydrogens of a methylene group adjacent to only one double bond.

Results obtained with a commercial Nickel catalyst are also reported for the sake of comparison in Table 4 (entry 9). Early stearic C18:0 formation and high trans-content are responsible for the very high pour point observed.

Nickel–Cerium mixed oxides modified by aluminium additives, have been proposed for the selective hydrotreatment of rapeseed oil [28]. Although the use of a ternary oxide allows a decrease in the extent of \(\text{cis}/\text{trans}\)-isomerization with respect to Ni–Ce-oxides and Ni alone, the hydrogenation has to be limited in order not to increase the C18:0 content, therefore reducing the improvement in oxidation stability.

4 Conclusions

Selective hydrogenation carried out with low loading copper catalysts under mild conditions could represent a valuable and efficient tool for feedstock composition standardization.

Actually, starting from methylesters with a very different fatty acids composition, it is possible to obtain mixtures with quite homogeneous composition in terms of unsaturation, thus giving materials suitable for different applications. The high activity of the catalytic system and the almost complete selectivity, give in principle the opportunity to tune and shut off the hydrogenation process, depending on the specifications requested for the product, just by following the hydrogen consumption. Moreover the catalyst is neither toxic nor pyrogenic, unlike Ni and Pd based ones.

This process provides the opportunity to plan a versatile protocol for the production of oleochemicals, useful to face not only price variations but also different supplying needs, depending on climatic and seasonal availability, thus making a wide portfolio of raw materials available without interfering with the food market.

The authors have declared no conflict of interest.

References


