Preparation of saturated and unsaturated fatty acid hydrazides and long chain *C*-glycoside ketohydrazones†

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Received 27th July 2010, Accepted 27th August 2010
DOI: 10.1039/c0gc00372g

A method is described to prepare both saturated and unsaturated fatty acid acyl hydrazides using a lipase as a catalyst. Hydrazides were generated from fatty acid methyl esters as well as directly from vegetable oils, and an organic co-solvent was not needed to maintain the integrity of the unsaturated fatty acids. Both *C. antarctica* lipase immobilized on acrylic resin and immobilized *M. miehei* lipase were used to catalyze the reaction, and they provided the desired acyl hydrazides with similar yields of 82.8% and 84.6%, respectively. Analysis of the products by MALDI-TOF-MS and GC-MS fragmentation pathways shows pure products free of starting methyl esters or triacylglycerols. These hydrazide molecules have been used, in conjunction with carbohydrate *C*-glycoside ketones, to prepare long chain *C*-glycoside ketohydrazones. This preparation does not require protecting groups or anomeric activation, and various *C*-glycoside ketohydrazones that retain the closed ring conformation of the parent sugars are described. These compounds have potential as renewable, sugar-based detergents in which the sugar moiety serves as the polar head group while the hydrazide alkyl chain is the non-polar component.

Triacylglycerols, or triglycerides, are a major class of naturally occurring organic compounds comprising of approximately 90% fatty acids and 10% glycerol.[1] They are produced in considerable quantities in both vegetable and algal oils and animal fats, making fatty acids a raw material with almost unlimited potential.[1]

Fatty acid hydrazides, which are *N*-acyl hydrazine derivatives, are well established compounds first mentioned in the literature in 1895.[2,3] Unsubstituted hydrazide derivatives of fatty acids were reported in the literature as early as 1914.[4] More recently, hydrazides have commonly been used to aid in spectroscopic identification of fatty acids.[5–8] In addition, their potential as corrosion inhibitors[9–11] and use for biomedical applications have been explored.[12–15]

Immobilized *Mucor miehei* lipase (Lypozyme®) and immobilized *Candida antarctica* lipase B (Novozyme® 435) have been used to prepare biodiesel (mono-alkyl fatty acid esters) by transesterification of vegetable oils using various types of short chain alcohols,[16–24] such as methanol, ethanol, or propanol.[16–17,19,21–22,24] Pre-treatment of the lipase with butanol, prior to subjecting it to reaction, has been shown to increase product yield.[25] Hydrophobic solvents such as heptane, cyclohexane, and toluene have been shown to preserve catalytic activity and increase efficiency of enzymatic conversion.[26] There are reports of alcoholysis of vegetable oils using a hydrophobic solvent such as petroleum ether,[24,27] hexane,[18,26] and cyclopentene.[28] However, increasing interest has been focused on a reaction route that does not include hydrophobic solvents such as the ones listed above.[16–17,19,21–23] Recently, fatty hydrazides were prepared enzymatically, in a similar manner to transesterification, directly from palm oils.[26] Synthesis was completed in a one-step reaction catalyzed by *Mucor miehei* lipase using hexane as a solvent.[26]

C-glycosides, derived from naturally occurring carbohydrates, have potential for uses as natural product building blocks and enzyme inhibitors.[29,30] Because their anomeric center has been transformed to a cyclic ether, *C*-glycosides are more stable towards degradation. There are minimal conformational differences between the *O*- or *N*-glycosides and the *C*-linked analogues, and they possess similar structural flexibility and pharmacological characteristics.[29,30] As such, a growing interest in this class of compounds has developed in recent years.

C-glycoside ketones have been prepared in aqueous alkaline media *via* a Knoevenagel condensation of unprotected reducing sugars with 2,4-pentanedione.[31–35] Attempts have been made to synthesize *C*-glycolipids by condensation of both symmetrical and asymmetrical β-diketones with longer alkyl chain length.[32] The target *C*-glycolipids were formed using longer reaction times, although as a mixture of products in low to moderate yields.[32] In addition, insolubility of the more aliphatic β-diketones in water required the use of an ethanol co-solvent.

Here we report that fatty acid hydrazides will react with *C*-glycoside ketones to form aliphatic ketohydrazones in high yields (Scheme 1).

This paper will describe the formation of acyl hydrazide intermediates from both fatty acid esters and from plant triacylglyceride oils. In addition, it describes the reaction of these acyl hydrazides with *C*-glycoside ketones to generate a novel family of *C*-glycoside ketohydrazones. These latter compounds

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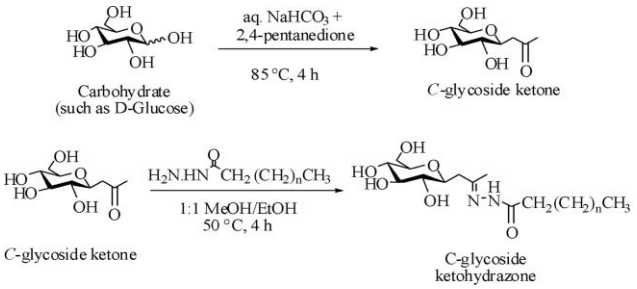
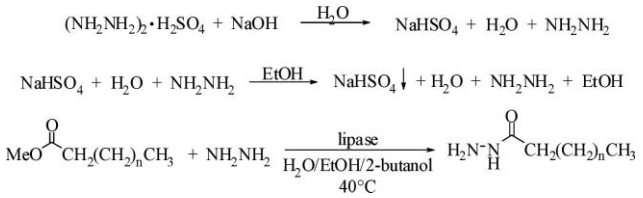
† Electronic supplementary information (ESI) available: Electron impact mass spectrometry characterization. See DOI: 10.1039/c0gc00372g



Scheme 1 General reaction for ketohydrazones preparation.



Scheme 2 Reaction to form hydrazides from fatty acid methyl esters from hydrazine hemisulfate salt.

have considerable potential as a new class of "green" sugar-based surfactants and detergents.

Results and discussion

Fatty acid hydrazides

Due to concerns about the safety, toxicity, and the costs associated with shipping free hydrazine it was prepared *in situ* as shown in Scheme 2. Hydrazine hemisulfate salt was dissolved in water followed by addition of NaOH to give aqueous hydrazine and sodium sulfate. Ethanol was added to the solution to precipitate the unwanted sodium sulfate. The sodium sulfate byproduct was removed by filtration to give free hydrazine in an ethanol/water solution. A known amount of hydrazine contained in the aqueous solution was then used in the synthesis of fatty acid hydrazides from both fatty acid methyl esters as well as directly from vegetable oils.

Fatty acid hydrazides were prepared from commercially available fatty acid methyl esters (FAMEs). This was first attempted without lipase by reacting FAMEs with aqueous hydrazine. While this route did produce the desired hydrazides, the reaction temperature was high at 100 °C and yields were low with less than 30% recovery. A more efficient and higher yielding route employing milder reaction conditions was desirable. Accordingly, we examined the use of two lipases, immobilized *Mucor miehei* and immobilized *Candida antarctica*, to catalyze the formation of hydrazides. Reaction of fatty acid methyl esters such as methyl caprylate, methyl laurate, methyl palmitate, and methyl oleate with hydrazine in the presence of *C. antarctica* lipase as a catalyst at 40 °C in a water : 2-butanol : ethanol (1 : 2 : 2) solvent mixture gave the corresponding hydrazides in good yields after 24 h (Fig. 1). Water and ethanol were used for solubility of the hydrazine and ester, while 2-butanol was chosen for pre-treatment of immobilized *C. antarctica* lipase. The lipase was recovered, rinsed with water, and saved for reactivation and reuse at a later time.[25]

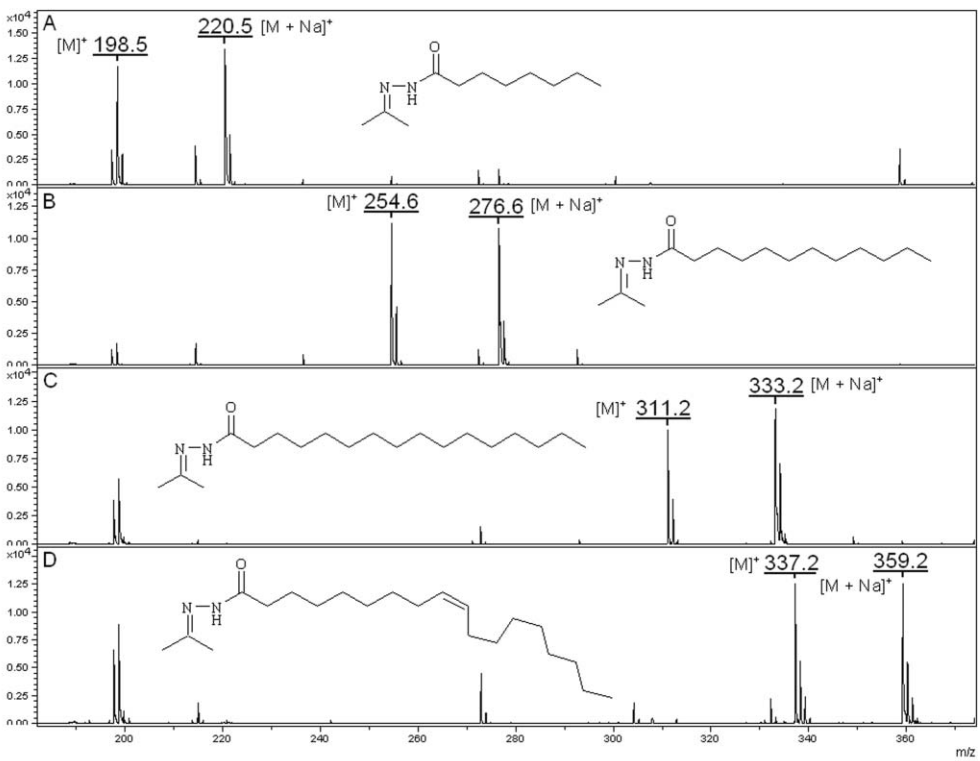


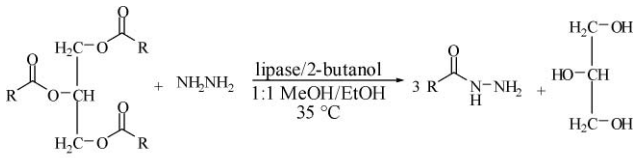
Fig. 1 MALDI-TOF-MS spectra showing characteristic $[M]^+$ and $[M + Na]^+$ peaks for acetone hydrazones prepared from (A) caprylic hydrazide (*m*/*z* 198.5, *m*/*z* 220.5); (B) lauric hydrazide (*m*/*z* 254.6, *m*/*z* 276.6); (C) palmitic hydrazide (*m*/*z* 311.2, *m*/*z* 333.2); and (D) oleic hydrazide (*m*/*z* 337.2, *m*/*z* 359.2).

Isolated fatty acid hydrazides from the lipase catalyzed reaction gave yields ≥ 77%. Because the fatty acid methyl esters and the fatty acid hydrazides have the same molecular weight, they were also analyzed by MALDI-TOF-MS as the corresponding acetone hydrazone and 3-heptanone hydrazone derivatives. This derivatization ensured the compounds synthesized were the target hydrazides, as ketones will not react with the fatty acid methyl esters. The acetone and 3-heptanone hydrazones were formed by adding the appropriate ketone to the fatty acid hydrazide dissolved in methanol and agitating. This proved a valuable tool in the structural determination of each of the fatty acid hydrazides synthesized since they also proved suitable for characterization by GC-MS based upon fragmentation data from electron impact mass spectrometry (EI-MS). Fig. 1 shows the MALDI-TOF-MS data for the acetone hydrazone derivatives.

These combined methods clearly establish the synthesis of the hydrazides from the starting methyl esters. As expected, the lipase catalyzes the reaction quite effectively at a lower temperature with increased yields. Furthermore, the lipase can be regenerated in a relatively simple process and used for additional reactions.[25]

Based on the success of the *C. antarctica* lipase to produce hydrazides, a reaction was carried out with methyl laurate to compare the lauric hydrazide yields produced by *M. miehei* lipase relative to *C. antarctica* lipase. Reactions were carried out in a side-by-side manner at 40 °C. Both lipases gave isolated yields of lauric hydrazide >80% free of the starting methyl ester. *M. miehei* gave a slightly better yield, 85%, than *C. antarctica*, 83%. MALDI-TOF-MS analysis of the acetone and 3-heptanone derivatives of each showed a clean product free of the starting ester. Since both lipases gave similar yields, *C. antarctica* was chosen for further use because of cost considerations.

In addition to hydrazides prepared from fatty acid methyl esters, hydrazides have been prepared directly from vegetable oils. Commercial vegetable oils (olive, sesame, and corn) were used without modification. Due to the fatty acid composition of the various oils, a mixture of fatty acid hydrazides were prepared from one vegetable oil source, as shown in Scheme 3. It is important to note that the triacylglycerol R groups may represent different acyl chains.



Scheme 3 General reaction to form acyl hydrazides from vegetable oil triacylglycerides.

As with the acyl hydrazides derived from individual fatty acid methyl esters, the hydrazides derived from vegetable oils were converted to the corresponding acetone and 3-heptanone derivatives. This derivatization facilitated analysis by MALDI-TOF-MS and GC-MS. Fig. 2 shows the spectra obtained for the acetone hydrazones derived from sesame oil, corn oil, and olive oil. It is interesting to note that olive oil appears to contain mostly saturated palmitic and stearic acid hydrazides while sesame and corn oil have a greater amount of the unsaturated oleic and linoleic acid hydrazides in accordance with the fatty acid compositions of the starting vegetable oils. This implies

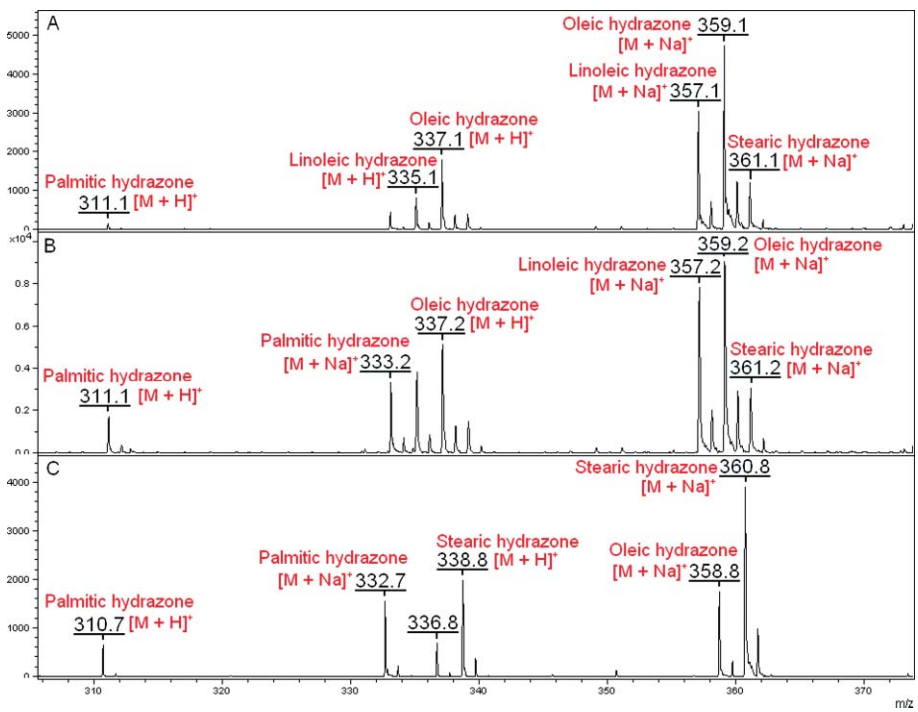


Fig. 2 MALDI-TOF-MS spectra for acetone hydrazones prepared from (A) sesame oil hydrazides, (B) corn oil hydrazides, and (C) olive oil hydrazides showing characteristic $[M + H]^+$ and $[M + Na]^+$ peaks for palmitic hydrazone, *m/z* 311.1 and *m/z* 333.2; oleic hydrazone, *m/z* 337.2 and *m/z* 359.2; linoleic hydrazone, *m/z* 335.1 and *m/z* 357.2; and stearic hydrazone, *m/z* 338.8 and *m/z* 361.2.

Table 1 *m/z* values for compounds of interest

Compound	$[M + H]^+$	$[M + Na]^+$
Starting *C*-glycoside ketones		
Glucose-*C*-glycoside ketone	221	242
Xylose-*C*-glycoside ketone	191	212
Rhamnose-C-glycoside ketone	205	226
Galacturonic acid-*C*-glycoside ketone	234	256
Lactose-*C*-glycoside ketone	383	404
Starting hydrazides		
Caprylic hydrazide	159	181
Lauric hydrazide	215	237
Palmitic hydrazide	271	293
Stearic hydrazide	299	321
Oleic hydrazide	297	319
Linoleic hydrazide	295	317
Hydrazone products		
Glucose-*C*-glycoside caprylic hydrazone	361	383
Glucose-*C*-glycoside lauric hydrazone	417	439
Glucose-*C*-glycoside palmitic hydrazone	473	495
Glucose-*C*-glycoside stearic hydrazone	501	523
Glucose-*C*-glycoside oleic hydrazone	499	521
Glucose-*C*-glycoside linoleic hydrazone	497	519
Xylose-*C*-glycoside lauric hydrazone	387	408
Rhamnose-*C*-glycoside lauric hydrazone	401	422
Galacturonic acid-*C*-glycoside lauric hydrazone	431	453
Lactose-*C*-glycoside lauric hydrazone	579	601

that the hydrazide components can be predicted and tailored to particular compositions based on the fatty acid profile of the starting vegetable oils.

It is important to note that not only saturated fatty acid hydrazides were produced, but also monounsaturated and polyunsaturated fatty acid hydrazides as well. Previous attempts to synthesize unsaturated fatty acid hydrazides from hydrazine and esters have been unsuccessful due to hydrogenation of the double bond in the presence of hydrazine.[15,36] In past literature, the use of a hydrophobic co-solvent such as cyclopentene, to protect the double bonds from hydrazine reduction, has been employed to form unsaturated hydrazides with success.[28] Unsaturated hydrazides can also be prepared by direct hydrazinolysis in an atmosphere of nitrogen; results were confirmed by TLC but no yields were reported.[37]

Long chain *C*-glycoside ketohydrazones

Carbohydrate *C*-glycoside ketones were prepared using standard methods.[31,33,35] With the use of an aqueous co-solvent, the fatty acid hydrazides reacted with the *C*-glycoside ketones quickly and under mild reaction conditions to produce the corresponding *C*-glycoside ketohydrazones. The described methodology affords the products cleanly without requiring chromatographic clean-up, and is amenable to a variety of fatty acid chain lengths and carbohydrate head groups.

Table 1 presents *m/z* values of glycoside ketone, acyl hydrazide, and ketohydrazone compounds expected to be present in reaction mixtures as observed by MALDI-TOF-MS.

Glucose-*C*-glycoside ketone was used to prepare ketohydrazones from a variety of fatty acid hydrazides. The desired hydrazide was added to an excess of glucose-*C*-glycoside ketone dissolved in 1 : 1 MeOH/EtOH and heated to 50 °C for 4 h. Glucose-*C*-glycoside ketone was used in ~2-fold excess to ensure complete reaction between the ketone and acyl hydrazide and to eliminate free hydrazide remaining in solution. MALDI-TOF-MS of the reaction products shows no acyl hydrazide starting material, indicating complete conversion to the ketohydrazone. The reaction was accomplished using hydrazides containing 8, 12, 16, and 18 carbon atoms.

This method of ketohydrazone formation was not only successfully implemented using hydrazides derived from individual fatty acid methyl esters, but also with mixtures of fatty acid hydrazides from vegetable oils. As vegetable oils produce hydrazides of various chain lengths, a mixture of *C*-glycoside ketohydrazones were formed as well. As can be seen from Fig. 3, the unique fatty acid profiles of the oils gave rise to different glucose-*C*-glycoside ketohydrazones, including those with both monounsaturated or polyunsaturated acyl chains. The double bonds from the oil hydrazides are preserved due to the mild nature of the reactions involved.

In addition to this method being generally applicable to a variety of fatty acid hydrazides, from both methyl esters and vegetable oils, it can be used to create *C*-glycoside ketohydrazones with different sugar head groups. Hence, *C*-glycoside ketones can be synthesized with various starting sugars.[33,35] General applicability was demonstrated using a pentose, 6-deoxyhexose, an acidic uronic acid, and a common disaccharide with lauric hydrazide, as shown in Fig. 4. These carbohydrate-*C*-glycoside ketones can be reacted in the manner described above to form *C*-glycoside ketohydrazones.

Experimental

Materials and general methods

Fatty acid methyl esters, hydrazine hemisulfate, sodium hydroxide pellets, and carbohydrates were purchased from Sigma–Aldrich. Immobilized *C. antarctica* lipase (lipase B, 10 000 U g^{-1}) expressed in *Aspergilus niger* and immobilized on acrylic resin, and immobilized *M. miehei* lipase (>30 U g^{-1}) were purchased from Sigma–Aldrich. Olive oil, corn oil, and sesame oil were purchased from a local grocery store.

MALDI-TOF mass spectra were recorded on a Bruker-Daltonic Omniflex instrument operating in reflection mode. Ion source 1 was set to 19.0 kV and source 2 was set to 14.0 kV with lens and reflector voltages of 9.20 and 20.00 kV, respectively. A 200-ns pulsed ion extraction was used. The instrument was calibrated externally on a dp series of malto-oligosaccharides. Samples (0.5 μL) were co-crystallized with the matrix (2,5-dihydrobenzoic acid) onto a conventional 49-place stainless steel target. Excitation was at 337.1 nm, typically at 80% of 150 μL maximum output, and 60 shots were accumulated.

GC-MS analyses were performed on an Agilent 6860 N Series gas chromatograph equipped with a 7683 Series autoinjector. The GC was interfaced with an Agilent 5973 Series mass-selective detector (MSD) configured in electron impact (EI) mode. Chromatography was accomplished with a fused silica capillary HP-1 column (30 m; 0.25 mm). Helium (18.6 ml min^{-1}) was used as the carrier gas. The oven temperature was ramped over a linear gradient from 120 to 250 °C at 5 °C

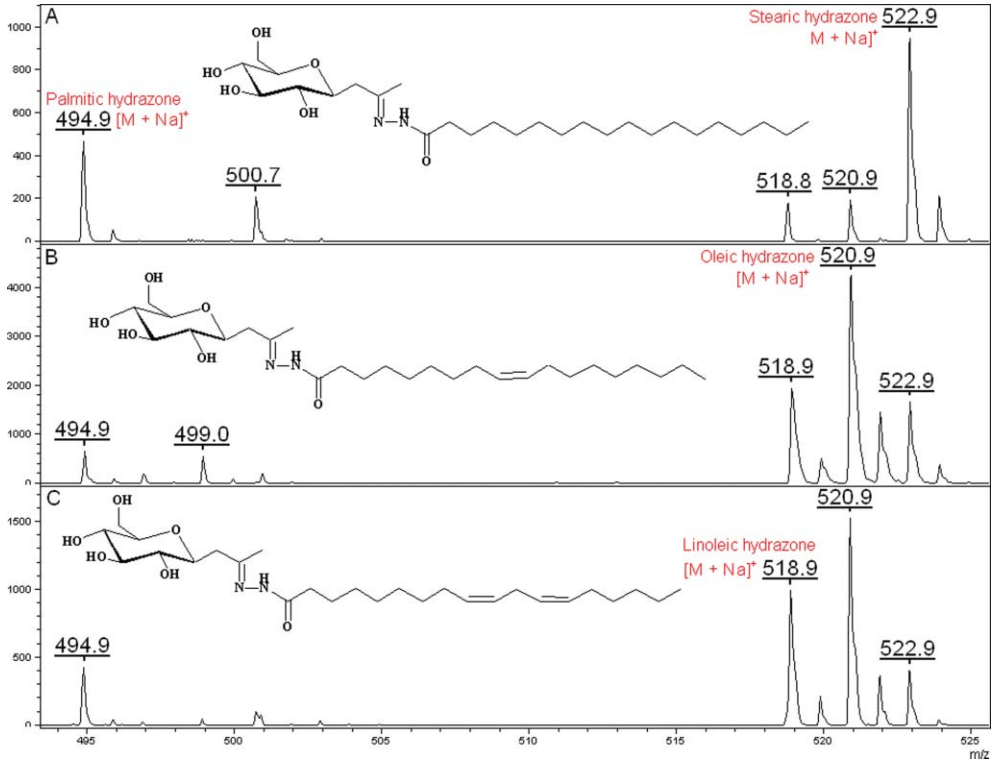


Fig. 3 MALDI-TOF-MS spectra for glucose-*C*-glycoside ketohydrazones prepared from (A) olive oil hydrazides, (B) sesame oil hydrazides, and (C) corn oil hydrazides showing characteristic $[M + Na]^+$ peaks for palmitic hydrazone (m/z 494.9), stearic hydrazone (m/z 522.9), oleic hydrazone (m/z 520.9) and linoleic hydrazone (m/z 518.9).

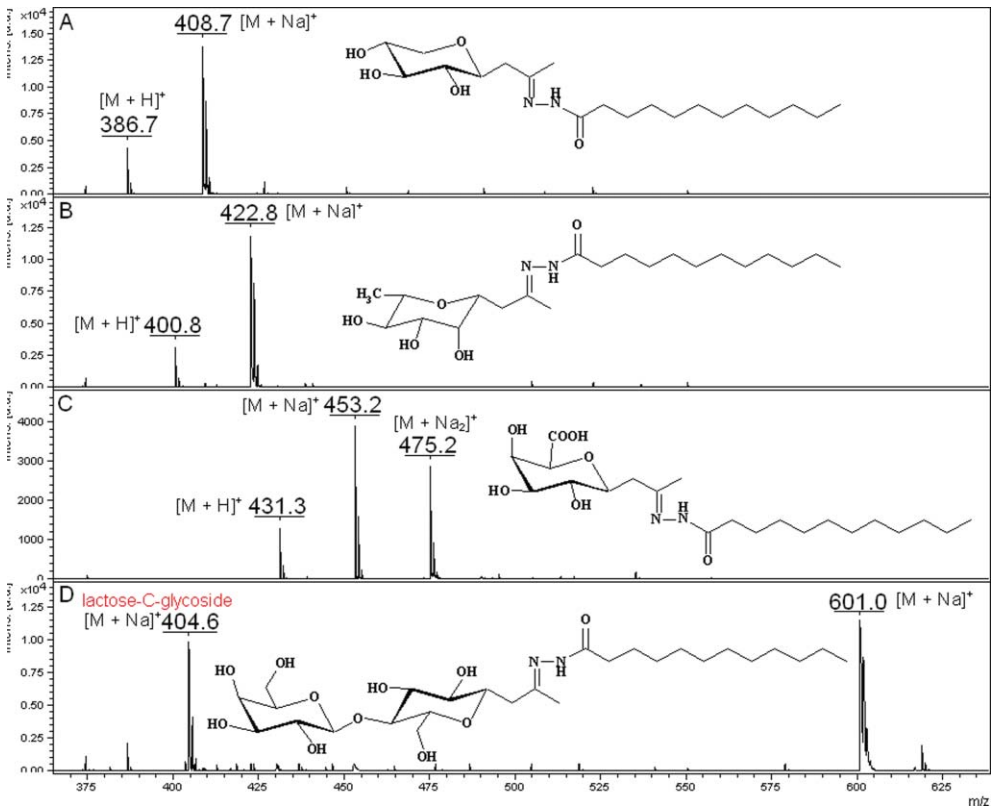


Fig. 4 MALDI-TOF-MS spectra showing characteristic $[M]^+$ and $[M + Na]^+$ peaks for lauric ketohydrazones prepared from (A) xylose-*C*-glycoside (m/z 386.7 and m/z 408.7), (B) rhamnose-*C*-glycoside (m/z 400.8 and m/z 422.8), (C) galacturonic acid-*C*-glycoside (m/z 431.3 and m/z 453.2), and (D) lactose-*C*-glycoside (m/z 579.0 and m/z 601.0). Galacturonic acid-*C*-glycoside hydrazone also has a sodium salt peak assigned as $[M + Na_2]^+$ at 475.2 m/z.

min^{-1}. Injector and detector/interface temperatures were 275 and 300 °C, respectively. Mass spectra were recorded in positive ion mode over the range m/z 45–550.

General procedure to form acyl hydrazides from methyl esters (no lipase). Hydrazine hemisulfate (0.801 g, 9.87 mmol) was dissolved in water (8 mL) and cooled in an ice bath. Sodium hydroxide pellets (0.401 g, 10.0 mmol) were added to the solution and stirred until completely dissolved. Ethanol (8 mL) was added to precipitate sodium sulfate impurities which were removed by vacuum filtration. To the resulting filtrate, methyl caprylate (445 μL, 2.47 mmol) was added and the mixture was heated (100 °C) for 2 h. The reaction was cooled and concentrated under reduced pressure to give caprylic hydrazide (0.082 g, 0.520 mmol, 20.6% yield) as a white solid. The product was identified by MALDI-TOF-MS and GC-MS analysis of the acetone and 3-heptanone hydrazone derivatives.

General procedure to form acyl hydrazides from methyl esters (*C. antarctica* lipase). Hydrazine hemisulfate (0.186 g, 2.29 mmol) was dissolved in water (1.0 mL) and cooled in an ice bath. Sodium hydroxide pellets (0.091 g, 2.28 mmol) were added to the solution and stirred until completely dissolved. Ethanol (3.0 mL) was added to precipitate the sodium sulfate impurities which were subsequently removed by vacuum filtration. To a suspension of *C. antarctica* lipase (0.115 g) in 2-butanol (2.0 mL) was added the hydrazine solution and methyl caprylate (0.164 mL, 0.910 mmol). The suspension was heated (40 °C) for 24 h, cooled, and lipase removed by vacuum filtration. The resulting filtrate was concentrated and dried under vacuum overnight to give caprylic hydrazide (0.111 g, 0.704 mmol, 77.4% yield) as an off-white solid. MALDI-TOF-MS analysis of the acetone and 3-heptanone hydrazone derivatives showed pure caprylic hydrazide with no trace of unreacted methyl ester. GC-MS analysis further confirmed product identification.

Commercial lipase comparison experiments

Lauric hydrazide (immobilized C. antarctica lipase). Hydrazine hemisulfate (0.373 g, 4.60 mmol) was dissolved in water (1.5 mL) and cooled in an ice bath. Sodium hydroxide pellets (0.184 g, 4.61 mmol) were added to the solution and stirred until completely dissolved. Ethanol (3.0 mL) was added to precipitate the sodium salt impurities, which were removed by vacuum filtration. To a suspension of *C. antarctica* lipase (0.201 g) in 2-butanol (3.0 mL) was added the hydrazine solution and methyl laurate (0.378 mL, 1.53 mmol). The suspension was heated (40 °C) for 24 h, cooled, and lipase removed by vacuum filtration. The resulting filtrate was concentrated and dried under vacuum overnight to give lauric hydrazide (0.272 g, 1.27 mmol, 83% yield) as an off-white solid. MALDI-TOF-MS analysis of the acetone and 3-heptanone hydrazone derivatives showed pure lauric hydrazide with no trace of unreacted methyl ester. GC-MS analysis further confirmed product identification.

Lauric hydrazide (immobilized M. miehei lipase). Hydrazine hemisulfate (0.388 g, 4.78 mmol) was dissolved in water (1.5 mL) and cooled in an ice bath. Sodium hydroxide pellets (0.192 g, 4.79 mmol) were added to the solution and stirred until completely dissolved. Ethanol (3.0 mL) was added to precipitate the sodium salt impurities, which were removed by vacuum filtration. To a suspension of *M. miehei* lipase (0.209 g) in 2-butanol (3.0 mL) was added the hydrazine solution and methyl laurate (0.393 mL, 1.60 mmol). The suspension was heated (40 °C) for 24 h, cooled, and the lipase removed by vacuum filtration. The resulting filtrate was dried under vacuum overnight to give lauric hydrazide (0.289 g, 1.35 mmol, 85% yield) as an off-white solid. MALDI-TOF-MS analysis of the acetone and 3-heptanone hydrazone derivatives showed pure lauric hydrazide with no trace of unreacted methyl ester. GC-MS analysis further confirmed product identification.

General procedure to acyl form hydrazides from vegetable oils. Sesame oil (2.033 g) and *C. antarctica* lipase (1.038 g) were weighed out into an Erlenmeyer flask. Ethanol (3.0 mL) was then added to make a slurry which was placed on an orbital shaker at 200 rpm and 28 °C for 24 h.

Prior to removing the lipase slurry from the orbital shaker, hydrazine hemisulfate (2.799 g, 34.5 mmol) was dissolved in water (20 mL) and cooled in an ice bath. To the cool solution, sodium hydroxide pellets (1.384 g, 34.6 mmol) were added and the mixture stirred to completely dissolve the pellets. Ethanol (30 mL) was added to precipitate sodium salt impurities which were removed by vacuum filtration. The hydrazine filtrate was retained.

The lipase/sesame oil slurry was filtered through a BD 5 mL leur-lock syringe with a Millex-SR 0.5 μm filter syringe and added directly into the hydrazine salt solution. A fine precipitate formed almost immediately. The mixture was placed on an orbital shaker at 200 rpm and 35 °C for 72 h. The solution was cooled to approximately 10 °C and the precipitate was filtered, collected, and dried under vacuum overnight to give a soapy lightly yellow solid. The acetone and 3-heptanone hydrazone derivatives were prepared and analyzed by MALDI-TOF-MS.

General procedure for the *C*-glycoside ketone formation. D-glucose (0.073 g, 0.408 mmol) was dissolved in sodium bicarbonate buffer (2 mL). 2,4-Pentanedione (750 μL, 7.30 mmol) was added and the reaction was heated at 80 °C (4 h) with occasional vortexing. The solution was allowed to cool to room temperature and extracted with EtOAc (2 × 2 mL); the organic layer was removed. To the aqueous layer, Dowex-50W H^+-form strong cation exchange resin (*ca.* 50 mg) was added and agitated by hand. The resin was removed by filtration and the filtrate was analyzed by MALDI-TOF-MS.

General procedure for the *C*-glycoside hydrazone formation. Lauric hydrazide (0.029 g, 0.137 mmol) was added to dried glucose-*C*-glycoside ketone (0.063 g, 0.269 mmol). The mixture was dissolved in 2 mL 1 : 1 MeOH/EtOH with vortexing and heat to 50 °C for 4 h. After cooling, the samples were concentrated to dryness and analyzed by MALDI-TOF-MS.

Conclusions

In conclusion, we have prepared fatty acid hydrazides from commercially available methyl esters and commercially available vegetable oils using lipase to catalyze the reaction. The methyl esters used varied from 8 to 18 carbons and were both saturated and monounsaturated. General applicability of this method to vegetable oils was demonstrated with extra-virgin olive oil,

sesame oil, and corn oil. The hydrazine hemisulfate salt was used to prepare hydrazine *in situ* and provides a less expensive and toxic alternative to aqueous hydrazine. No organic solvents were needed in the vegetable oil reactions, as in previous reports.[18,24,26–28] Moreover, mono- and polyunsaturated fatty acid hydrazides were prepared successfully. In addition, a general and green method has been developed to produce hydrazones of carbohydrate-*C*-glycoside ketones using the prepared fatty acid hydrazides. Both the carbohydrate and the aliphatic, fatty acid portion can be manipulated to create a wide variety of molecules. No activation of the anomeric center is needed, and protection and deprotection of the carbohydrate is unnecessary. The reaction is carried out in aqueous buffer and the integrity of the closed-ring parent sugar is maintained. The nature of the acyl hydrazones gives these molecules potential for use as biodegradable, plant-derived surfactants. Further investigation is ongoing.

Acknowledgements

The authors declare no competing financial interests. We would like to thank Trina Hartman for technical assistance. Mention of trade names or commercial products in this article is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture.

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