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ORIGINAL PAPER

Copper and Iron Determination with [*N*,*N*′-Bis(salicylidene)-2,2′-dimethyl-1,3-propanediaminato] in Edible Oils Without Digestion

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Abstract A new method for the determination of copper(II) and iron(III) in liquid edible oils which does not require a digestion step was developed. The suggested method involves extraction of metals with [*N*,*N*′-bis(salicylidene)-2,2′-dimethyl-1,3-propanediaminato] (LDM) followed by flame atomic absorption spectrometry measurement. As a first step, metal complexes of copper(II) and iron(III) ions with LDM were investigated spectrophotometrically. After the analytical properties and experimental conditions of the complexation had been determined, these findings were used to determine the extraction period as a second step. Experimental conditions were optimized using a central composite design. Optimum conditions for Cu(II) and Fe(III) extractions from oil were found: the ratios of the volume of Schiff base solution used to the mass of oil ($V_{\mathrm{LDM}}/m_{\mathrm{oil}}$; mL g^{-1}) were 0.76 and 1.19 mL g^{-1}, the stirring times were 73 and 67 min, and the temperatures were 31 and 28 °C, respectively. The developed extraction and determination method was tested on certified reference materials; the recovery percentages were found to be 99.4 ± 2.8 and 100.2 ± 5.6 for Cu(II) and Fe(III), respectively. The suggested method was performed on real samples such as olive oil, sunflower oil, corn oil, canola oil and recovery values between 97.2–102.1 for Cu(II) and 94.5–98.6 for Fe(III) were determined. It was concluded that the developed method has some advantages over the common traditional method including rapidity, sensitivity, accuracy, reduced risk and cost.

Keywords Edible oil · Iron · Copper · [*N*,*N*′-bis(salicylidene)-2,2′-dimethyl-1,3-propanediaminato] · Schiff base · Flame atomic absorption spectrometry

Introduction

Olive oil and its components have well known nutritional benefits. It is widely known that some metals such as Cu, Fe, Zn, Ni, Cr, Co and Mn catalyze oxidation, and even at low levels of concentration, cause rancidity in olive oil. The formations of peroxides, aldehydes, ketones and other components may occur as the results of these oxidation reactions. Therein lies the importance of the determination of metals in olive oil.

Most techniques for the determination of metals in edible oils require sample pretreatment. According to the literature, microwave digestion of oils for the determination of some metals is widely used with highly sensitive instruments such as ICP-OES or ICP-MS [1–5]. Additionally, preconcentration techniques appropriate for the analyte may be required with a digestion procedure, making the whole procedure time consuming. When dry ashing is used as the method of digestion for edible oils, sample dilution is minimized more than microwave digestion, the risk of contamination is too high and precision is not as good [6]. Extraction with acids can also be used for analyzing metals in olive oil. It's disadvantage is that the precision of the extraction efficiency is not as good. When ET-AAS or ICP are used for the determination of metals in edible oils, a rapid pretreatment is possible by dilution with organic solvents such as methyl isobutyl ketone (MIBK).

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However, plasma stability and detection limits are not as good as when aqueous solutions are used [7–12].

Schiff bases, which have good metal complexing capabilities, have been used as ligands in metal complexes for recent analytical applications [13–22]. The use of Schiff bases as a radiological material, liquid crystal material or analytical separator has been documented [23, 24]. An interesting attribute of Schiff bases and their complexes is their antimicrobial and antifungal activity [25, 26].

In the present work, a simple, cheap, rapid, sensitive and accurate method for the determination of iron and copper in liquid edible oil was developed. Iron and copper in oil samples were extracted from the oil phase to the aqueous phase without digestion, using [*N*,*N*′-bis(salicylidene)-2,2′-dimethyl-1,3-propanediaminato] as a Schiff base ligand. The Schiff-base ligand used in the present work is shown in Fig. 1.

To optimize the conditions for metal extraction from oils, namely the ratio of Schiff base/olive oil, stirring time and temperature by a central composite design method was employed. The developed extraction technique for the determination of copper and iron in liquid edible oils can be used as a more efficient, cheap, rapid, sensitive and accurate method as compared to conventional methods in which time consuming digestion or metal extraction steps are involved.

Materials and Methods

Chemicals

A Merck Titrisol 109972 iron stock solution (1,000 mg iron in mL; $FeCl_3$ in 15% HCl) and copper stock solution (1,000 mg copper in mL; $CuCl_2 \cdot 2H_2O$ Merck) were used for preparing the standard solutions. Conostan iron standard (5,000 µg g^{-1}; code number: 354770) and Conostan copper standard (5,000 µg g^{-1}; code number: 687850) were used as certified reference materials (CRM) for optimization of experimental conditions and testing the improved method. [*N*,*N*′-bis(salicylidene)-2,2′-dimethyl-1,3-propanediaminato] (LDM) was synthesized and the structure of this Schiff base was clarified by Kurtaran et al. [27]. Stock solution of Schiff base was prepared by dissolving 0.1552 g LDM in 100 ml of 88% (v/v) ethanol–water. Appropriate amounts of stock solution were used for the preparation of the standard Schiff base solution (1×10^{-3} mol L^{-1}). Stock and standard solutions of LDM were kept in polyethylene containers to protect them from the light and temperature.

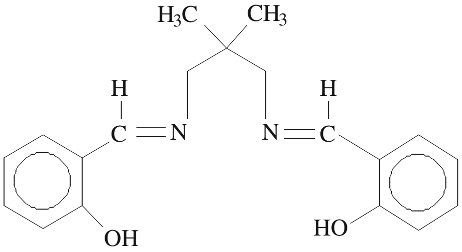

Fig. 1 The molecular structure of [*N*,*N*′-bis(salicylidene)-2,2′-dimethyl-1,3-propanediaminato] [27]

HCl (Merck) and NaOH (Merck) for pH 1, 2, 3; sodium acetate/acetic acid (Riedel-de Haen) for pH 4, 5; tris(hydroxymethyl)aminomethane (Merck) for pH, 6, 7; ammonia/ammonium nitrate (Merck) for pH 8, 9, 10, 11 and 12 were used to adjust the pH of the medium. All the reagents were analytical grade and doubly distilled water was used throughout.

Apparatus

A Varian Cary 1E UV–Vis spectrophotometer with 1.0-cm quartz cells was used to study the spectral properties of ligand and metal–ligand complexes. Copper and iron determinations in extracts were made by using a Unicam 929 A flame atomic absorption spectrometer (FAAS) equipped with deuterium background correction. The hollow cathode lamps for iron and copper were manufactured by the Koto Electric Co. Ltd and Unicam Analytic Systems, respectively. The FAAS operation conditions found to be convenient for each metal are given in Table 1. A Nel pH meter, Nüve heating bath and Heidolph magnetic stirrer were also used.

Procedures

All the spectral studies were performed in 88% (v/v) ethanol–water. The solutions of ligand, metal and complex used in the experiments were incubated at 25 °C. The absorption spectra of Schiff base, metal and a mixture of Schiff base with metal ions (Cu(II) and Fe(III)) were analyzed in order to reveal the most appropriate wavelengths. Figure 2 shows the absorption spectra of the solutions of 1×10^{-3} mol L^{-1} for the ligand and the complexes of each metal. As can be seen from Fig. 2,

Table 1 Operation conditions for iron and copper in FAAS

Parameters	Cu	Fe
Wavelength (nm)	324.8	248.3
Spectral band width (nm)	0.5	0.2
Lamp Current (mA)	3.5	5.0
Fuel flow rate (L min^{-1})	0.70	0.70
Flame height (mm)	13	13

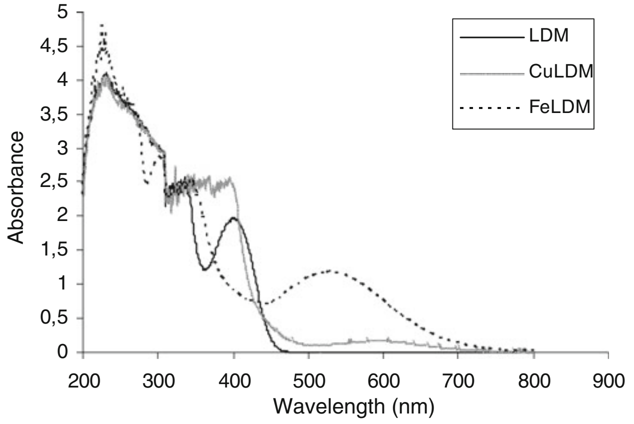

Fig. 2 The absorption spectra of LDM and complexes (Cu-LDM; Fe-LDM)

the most appropriate wavelengths of the complexes are 363 nm for Cu and 529 nm for Fe.

Kinetic studies were carried out to observe the period of the formation of metal complexes. The absorbances of the solutions prepared by mixing a solution of 1×10^{-3} mol L^{-1} ligand with that of 1×10^{-3} mol L^{-1} metal ions were recorded for 60 min. Five minutes was determined to be the time required to obtain a constant absorbance. In that process, experiments were performed at 363 and 529 nm for Cu and Fe, respectively.

The absorbance of metal complexes at different pH values was measured against the reagent blank with a UV–Vis spectrophotometer at their selected wavelengths. The ratio of the buffer solution volume to the final solution volume was 1:10 and the same amounts of buffer solutions were added for each solution used in the studies for the adjustment of pH.

Optimization of Experimental Conditions

To determine the optimum conditions in the procedure of extracting metals from oil phase to aqueous phase, central composite design was applied [28, 29]. Factors influencing the extraction efficiency of metals studied in the present work were the ratio of the volume of the Schiff base solution used to the amount of oil (V_{LDM}/m_{oil}; mL g^{-1}), the stirring time and the temperature. Ranges determined were 0.5–1.5 mL g^{-1}; 30–90 min; 20–40 °C for the first, second and third factors, respectively. Table 2 shows the factors, the levels and their values.

Table 2 Levels and the values of levels used in Central Composite Design

Levels	−1.682	−1	0	+1	+1.682
X_1 (1st factor)					
V_{LDM}/m_{oil} ratio (mL g^{-1})	0.159	0.5	1	1.5	1.841
X_2 (2nd factor)					
Stirring time (min)	9.56	30	60	90	110.46
X_3 (3rd factor)					
Temperature (°C)	13.18	20	30	40	46.82

In this study, 20 experiments were carried out to the extent of the Central Composite Design. Analytes (Cu(II), Fe(III)) concentrations in CRMs were 20 mg kg^{-1}. The metal contents of the extracts obtained from each experiment were determined by FAAS using the standard addition calibration method. The absorbance values obtained with FAAS were used to establish recovery values for the extraction of metals from oil. The calculated values of 1/(100 − Recovery %) were considered as response values (*y*) in Central Composite Design procedure. A mathematical matrix (*X*) was established for the determination of the parameters to be changed for each experiment.

b Values were calculated by applying to the *X* matrix. *y* equations (Eqs. 1 and 5 for Cu(II) and Fe(III), respectively) were constructed based on the *b* values. The values for X_1, X_2 and X_3 which makes the *y* equations zero were calculated as optimum conditions.

Application of the Method

The improved present method was applied to some liquid edible oils under the optimum experimental conditions. Certain levels of CRM were added to the oil samples, and the final concentration of the added metal standards was adjusted to 20 mg kg^{-1}. The oil sample and Schiff base (in ethanol/water) solutions were mixed at optimum V_{LDM}/m_{oil} ratio and stirred under the optimum conditions. The ethanol/water phase including the metal–LDM complex was separated and then the concentrations of Cu(II) and Fe(III) were determined by FAAS.

Results and Discussion

From the absorption spectra of LDM, Cu-LDM and Fe-LDM at pH 4.0 in Fig. 2, the maximum absorbance values were observed at 401, 363 and 529 nm, respectively. The composition of complexes of both metal ions was determined by a continuous variation method. Job's plot for copper and iron complexes confirmed a 1:1 (Metal:LDM) composition for both of the complexes. Absorption measurements were performed 5 min after the mixing reagent as determined by the equilibrium time experiments.

The Effect of pH on the Complexes

Adjustment of pH is necessary for the determination of the complexation ratio of the Schiff base and the metals.

Owing to the destruction of the structures of complexes at pHs <2 and the existence of the possibility of saponification of oil and precipitation of metal hydroxides at pHs >7, the pH range of 2–8 was evaluated to determine the optimum pH for complexation. According to the results obtained, pH 4 was chosen to be the optimum (Fig. 3).

The Optimization of Conditions for Metal Extraction from Oils

Experimental conditions for the suggested method in this work should be optimized in order to get the most efficient results. Results appearing in Table 3 were used in the central composite design. To the given amount of oil samples containing 20.0 mg L^{-1} Cu(II) or Fe(III) standards, a certain volume of 1×10^{-3} M LDM solution was added. After stirring for the desired period of time at the optimum temperature, the aqueous phase was separated and its metal concentration was determined by FAAS. The optimization of $V_{\mathrm{LDM}}/m_{\mathrm{oil}}$ ratio, stirring time and temperature was carried out at the conditions corresponding to code values given in Table 2.

By using the data in Table 3 in the central composite design standard procedure [28, 29], a y equation was obtained for Cu(II) as following:

$$y = 0.074479x_1 - 0.09842x_2 - 0.00327x_3 + 0.0065x_1^2 + 0.027201x_2^2 + 0.251628x_3^2 - 0.15978x_1x_2 + 0.080751x_1x_3 - 0.07861x_2x_3 - 0.1646x_1x_2x_3 \quad (1)$$

By equalization of the derivatives of Eq. 1 in terms of X_1, X_2, X_3 to zero, respectively, we obtain Eqs. 2–4.

$$\frac{\mathrm{d}y}{\mathrm{d}x_1} = 0.074479 + 0.013x_1 - 0.15978x_2 + 0.080751x_3 - 0.1646x_2x_3 = 0 \quad (2)$$

$$\frac{\mathrm{d}y}{\mathrm{d}x_2} = -0.09842 + 0.054402x_2 - 0.15978x_1 - 0.07861x_3 - 0.1646x_1x_3 = 0 \quad (3)$$

$$\frac{\mathrm{d}y}{\mathrm{d}x_3} = -0.00327 + 0.503256x_3 + 0.080751x_1 - 0.07861x_2 - 0.1646x_1x_2 = 0 \quad (4)$$

Similarly, the y equation was obtained for Fe(III) by using the data in Table 3 in the central composite design standard procedure. The constructed y Eq. 5 is given as the following:

$$y = -0.04406x_1 + 0.052283x_2 + 0.210066x_3 + 0.086966x_1^2 + 0.089654x_2^2 + 0.250638x_3^2 - 0.33978x_1x_2 - 0.17359x_1x_3 + 0.030373x_2x_3 - 0.47376x_1x_2x_3 \quad (5)$$

Equalization of the derivatives of Eq. 5 in terms of X_1, X_2, X_3 to zero, respectively, gave Eqs. 6–8 for Fe(III).

$$\frac{\mathrm{d}y}{\mathrm{d}x_1} = -0.04406 + 0.173932x_1 - 0.33978x_2 - 0.17359x_3 - 0.47376x_2x_3 = 0 \quad (6)$$

$$\frac{\mathrm{d}y}{\mathrm{d}x_2} = 0.052283 + 0.179308x_2 - 0.33978x_1 + 0.030373x_3 - 0.47376x_1x_3 = 0 \quad (7)$$

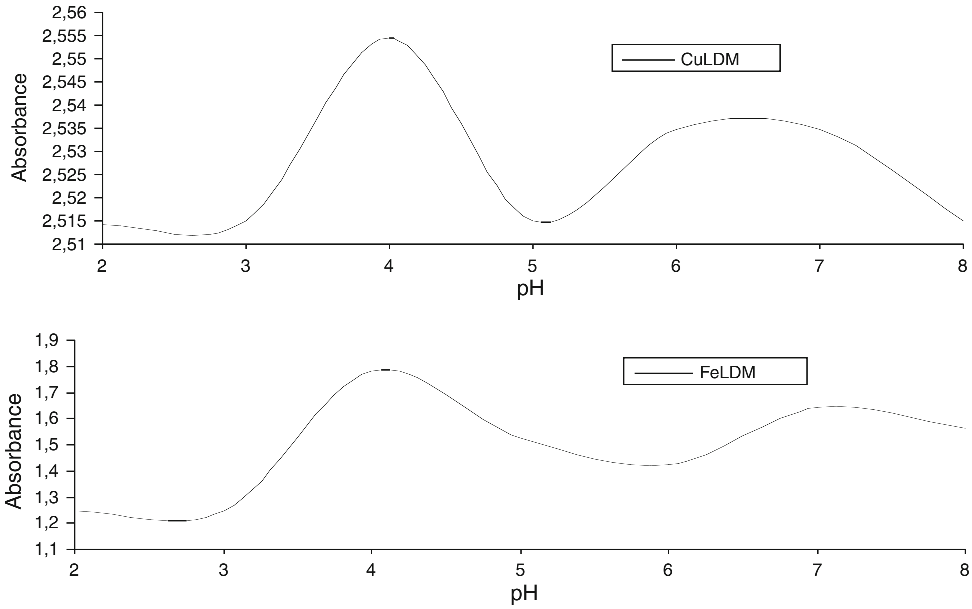

Fig. 3 The effect of pH on the complexes

Table 3 Recovery and response values for the extraction of Cu(II) and Fe(III) from olive oil

Experiment	X_1 V_{LDM}/m_{oil} (mL g^{-1})	X_2 Time (min)	X_3 Temp (°C)	Cu(II)		Fe(III)	
				Rec %	Response	Rec %	Response
1	1/2	30	20	103.4	0.296	101.2	0.801
2	1.5	30	20	101.6	0.625	82.3	0.056
3	1/2	90	20	104.7	0.211	93.0	0.166
4	1.5	90	20	103.6	0.282	87.6	0.080
5	1/2	30	40	76.8	0.043	67.5	0.031
6	1.5	30	40	107.5	0.133	102.1	0.481
7	1/2	90	40	111.8	0.085	103.6	0.274
8	1.5	90	40	100.9	1.136	99.3	1.389
9	1	60	30	96.2	0.260	99.5	2.155
10	0.159	60	30	31.8	0.015	36.7	0.016
11	1.841	60	30	108.8	0.113	107.3	0.137
12	1	9.56	30	58.4	0.024	52.6	0.021
13	1	110.46	30	118.4	0.054	117.9	0.056
14	1	60	13.18	91.8	0.122	84.3	0.064
15	1	60	46.82	86.4	0.074	65.1	0.029
16	1	60	30	98.0	0.992	98.2	0.563
17	1	60	30	97.9	0.473	97.7	0.440
18	1	60	30	100.3	3.906	97.9	0.473
19	1	60	30	101.3	0.762	96.2	0.266
20	1	60	30	99.4	1.602	99.3	1.389

$$\frac{\mathrm{d}y}{\mathrm{d}x_3} = 0.210066 + 0.501276x_3 - 0.17359x_1 + 0.030373x_2 - 0.47376x_1x_2 = 0 \qquad (8)$$

Equations 2–4 for Cu and 6–8 for Fe were solved using Derive 6 computer software and code values of X_1, X_2 and X_3 were obtained. These code values were transformed to the true values providing the optimum conditions of the factors. The results are given in Table 4.

Application of the Improved Extraction Method to the Certified Reference Materials

The extraction procedure has been applied to the CRMs under the optimum experimental conditions given in Table 4. As seen in Table 5, the recovery percentages are satisfactory enough to extract and determine Fe(III) and Cu(II) in oil without any digestion or extraction steps. LDM is suggested for the extraction of Cu(II) and Fe(III) from liquid edible oils as an appropriate ligand under the optimum experimental conditions.

The limit of detection (LOD) of the suggested method for Fe and Cu was found to be 6.0 and 2.0 mg kg^{-1} respectively. The recovery percentages 99.4 (±2.8) and 100.2 (±5.6) obtained by application of the method to CRMs show that the suggested method is very suitable for liquid edible oils for the determination of Cu(II) and Fe(III).

Table 4 Optimum extraction conditions for Cu(II) and Fe(III) by LDM

Metal	Optimum conditions		
	V_{LDM}/m_{oil} ratio (mL g^{-1})	Stirring time (min)	Temperature (°C)
Cu(II)	0.76	73	31
Fe(III)	1.19	67	28

Application of Real Samples

To test the applicability of the developed procedure, it was applied to the extraction and determination of Cu(II) and Fe(III) content from different edible oil samples by FAAS. Oil samples were collected from Turkish markets. As can be seen from Table 6, the results for real oil samples were acceptable.

Study of Interferences

The effects of foreign metal ions on the extraction of Cu(II) and Fe(III) ions from oil to the aqueous phase were investigated by measuring the absorbance of solutions containing 3 mg L^{-1} analyte in the presence of foreign ions in the range of 3–3,000 mg L^{-1}. Tolerance limits of foreign ions were taken as that value which caused an error of not more than ±5% in the absorbance differences. The

Table 5 Recovery values for the extraction of Cu(II) and Fe(III) from oil (CRM) under the optimum experimental conditions ($n = 10$)

CRM	Certified value (μg g^{-1})	Founded value (μg g^{-1})	Mean recovery (%)	Standard deviation
Conostan 687850 (Cu(II) standard)	25.9	25.7	99.4	2.8
Conostan 354770 (Fe(III) standard)	26.1	26.1	100.2	5.6

Table 6 Recovery values for the extraction of Cu(II) and Fe(III) from various oil samples

Samples	Certified value (μg g^{-1})	Value found (μg g^{-1})	Mean recovery (%)	Standard deviation
Olive oil				
Cu	20.0	19.9 ± 0.2	99.8	1.2
Fe	20.0	19.7 ± 0.2	98.6	0.8
Sunflower oil				
Cu	20.0	19.4 ± 0.2	97.2	0.8
Fe	20.0	18.9 ± 0.2	94.5	0.8
Corn oil				
Cu	20.0	20.4 ± 0.3	102.1	1.3
Fe	20.0	19.3 ± 0.3	96.7	1.7
Canola oil				
Cu	20.0	19.5 ± 0.2	97.7	0.7
Fe	20.0	19.0 ± 0.3	95.2	1.5

tolerance limits for Na, Mn and Zn on 3 mg kg^{-1} Cu(II) solutions were 150, 1,500 and 30 mg kg^{-1}, respectively. The tolerance limit for Cu on 3 mg kg^{-1} Fe(III) was 150 mg kg^{-1}.

Conclusion

In the present work, a simple extraction procedure without digestion was developed for the determination of Cu and Fe in liquid edible oils. Cu and Fe concentrations of liquid edible oils were determined by FAAS after the extraction of both metals with LDM into the aqueous phase. The metal determination methods in oils require sensitive instruments such as ICP-OES and GF-AAS, are expensive and also require an acid digestion or extraction step which have some disadvantages such as risk of explosion or contamination as well as being time consuming, etc. The suggested determination strategy after the extraction step with LDM were found to have some advantages: (1) no need to use expensive instruments, i.e. ICP-OES or GF-AAS, (2) protection from some interferences caused by highly organic matrices of oil, (3) greatly reduced explosion risk during decomposition, (4) high recovery and sensitivity values, and also (5) rapid and cheap.

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