Oxysterol Formation in Egg Powder and Relationship with Other Quality Parameters

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To determine whether the spray-drying temperature influences oxysterol formation in powdered egg, three temperature conditions were assayed. Moreover, the relationships between oxysterol formation and other parameters of alteration (egg fat absorption at 232, 270, and 303 nm; color loss; and Maillard browning intensity) were studied. Formation of 7β-hydroxycholesterol and 7-ketocholesterol during the spray-drying process was much greater than formation of cholesterol 5α,6α-epoxide, cholestanetriol, and 25-hydroxycholesterol. Formation of oxysterols at T_A (180–120 °C; inlet–outlet temperatures) and that at T_B (193–128 °C) were similar but lower than at T_C (231–142 °C). Thus, there is a critical temperature between T_B and T_C at which the oxysterol formation increases significantly. In addition, this formation is well correlated with the rest of the alteration parameters studied.

Keywords: *Egg powder; spray-drying temperature; oxysterols; oxidation; Maillard browning*

INTRODUCTION

The system used to obtain dried egg products determines their quality, and pan-drying, foam-drying, freeze-drying, and spray-drying are the most usual (Bergquist, 1964, 1977). Freeze-drying has been used only as a research tool, due to its high cost, although, in contrast, it is the system that supplies the best quality because it is easy to reconstitute the liquid egg and deterioration during the process is negligible. The presence of oxysterols (OS) in freeze-dried egg is not detected (Fontana *et al.*, 1992; Tsai and Hudson, 1984) or is minimum (Morgan and Armstrong, 1989; Nourooz-Zadeh and Appelqvist, 1987).

Spray-drying is frequently used to obtain powdered eggs. In this case, the presence of OS has been widely confirmed, and their formation depends on two main factors: first, the air heating system used, direct or indirect heating (Missler *et al.*, 1985; Morgan and Armstrong, 1987, 1992; Tsai and Hudson, 1985), and second, the inlet and outlet temperatures (Morgan and Armstrong, 1987, 1992; Tsai and Hudson, 1985). When the air is heated indirectly, the formation of OS in the dried egg is lower than when direct heating is applied. According to some authors, it is due to the formation of nitrogen oxides (NO and NO_2) in the air directly heated by passage through a natural gas flame, and these compounds have an oxidative effect on the product (Missler *et al.*, 1985; Morgan and Armstrong, 1987, 1992; Tsai and Hudson, 1985). Other factors probably influence the oxidation and the whole quality of dried egg and, in consequence, should be monitored during spray-drying. These factors are the type of atomizer and the residence time of the product inside the spray-drying chamber (Tsai and Hudson, 1985). Moreover, the presence of OS in dried egg products presumably obtained by spray-drying has been reported by other authors (Pie *et al.*, 1990; Van de Bovenkamp *et al.*, 1988).

The aim of this paper is to study the influence of the spray-drying temperature on the OS formation in the egg and to examine possible correlations between OS formation and other deterioration processes affecting dried egg quality, such as fatty acid oxidation, color loss, and browning. Color loss due to the oxidation of carotenoids and Maillard browning are chosen because they are responsible for the main sensorial defect in powdered egg, and fatty acid oxidation was studied to search for a possible relation with the cholesterol oxidation process. For the study of the evolution of lipid oxidation, the determination of the fat UV absorptions (232, 270, and 303 nm) was chosen, since the presence of polyunsaturated fatty acid in egg fat is high and other chemical indices are less useful for this purpose. Maillard browning development was also chosen as a quality parameter, since it is a characteristic reaction that can occur in powdered egg due to the presence of protein and glucose.

MATERIALS AND METHODS

Sample Preparation. Six frozen egg samples were used for the application of the spray-drying process. A 10 kg container of each frozen egg was thawed and homogenized for 1 min, at 20 000 rpm, by a homogenizer Ystral electric drive 10/20 3000 (Liverpool, U.K.), and then an aliquot of 650 g was taken from each one. A part of the aliquot was used to determine moisture, color, fat UV absorption, and cholesterol and OS contents, as reference values. The rest of the aliquot was stored at −20 °C until spray-drying. Just before spray-drying, the rest of the aliquot was homogenized again, for 30 s at 20 000 rpm, and then divided into three parts, which were subjected to three temperature conditions of spray-drying (all samples were diluted by adding 25% of distilled water before spray-drying to facilitate the atomizer feeding).

Spray-Drying Conditions. All egg samples were processed in a Niro atomizer A/S (Copenhagen, Denmark) equipped with an electric heater, with a feed rate of 10 mL/min, an air pressure of 6 kg/cm^2, and an egg powder residence time in the atomizer of 25 min. Inlet and outlet temperatures were fixed simultaneously by controlling the air flow through the system.

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Three temperature conditions were assayed (T_A, inlet = 180 °C, outlet = 120 °C; T_B, inlet = 193 °C, outlet = 128 °C; and T_C, inlet = 231 °C, outlet = 142 °C). These three conditions are within the range of temperatures usually applied in experimental studies on egg spray-drying processes (Morgan and Armstrong, 1987). However, the current tendency is to use the lowest temperature possible (Bergquist, 1964, 1977; Tsai and Hudson, 1985). Conditions A and B fall in the higher range of temperatures used commercially, and condition C is outside this range.

As a result of this experimental design, 18 dried egg samples were obtained from the 6 frozen egg samples, in which the same analytical determinations that had been carried out in frozen egg samples were performed (moisture, color, fat UV absorption, and OS contents), in addition to the Maillard browning development, except for three dried egg samples proceeding from one of the frozen egg samples, in which only moisture and OS contents were determined because of the low sample amount available.

Reagents and Standards. The solvents used were of the following origin and quality: chloroform, methanol, diethyl ether, and acetone (all of ACS grade), cyclohexane (UV–IR), and hexane (for analysis) were from Panreac (Barcelona, Spain); ethyl acetate (ACS grade) and the dried pyridine (maximum 0.01% water, for analysis) were from Merck (Darmstadt, Germany).

Other reagents used were as follows: sea sand, trichloroacetic acid, sodium hydroxide, and anhydrous sodium sulfate (all for analysis) supplied by Panreac; and Sylon BTZ [*N*,*O*-bis(trimethylsilyl)acetamide/trimethylchlorosilane/*N*-trimethylsilylimidazole, 3:2:3, for research], in 0.1 mL glass ampules, from Supelco, Inc. (Bellefonte, PA). Silica Sep-Pak cartridges were supplied by Waters, Millipore Division (Milford, MA).

Standards of cholesterol (>99%, by GC) and β-carotene (>97%, by spectrophotometry) were supplied by Merck, and 5α-cholestane (99%, by GC) was supplied by Supelco. All other standards were from Sigma Chemical Co. (St. Louis, MO): cholesterol 5α,6α-epoxide (α-CE) (99%, by TLC), 7β-hydroxycholesterol (7β-HC) (99%, by TLC), cholestanetriol (CT) (>97%, by GC), 7-ketocholesterol (7-KC) (>99%, by HPLC), 25-hydroxycholesterol (25-HC) (>98%, by TLC), and 19-hydroxycholesterol (19-HC) (>99%, by TLC). All of these standards were weighed, with an accuracy of 0.01 mg, and were made up as ethyl acetate solutions.

Moisture Determination. This was performed by desiccation of an aliquot of the egg sample (4 g of liquid egg or 1.8 g of powdered egg) in an oven at 105 °C until constant weight (Leatherhead Food Research Association, 1987). In liquid egg samples desiccation was performed with the addition of sea sand. All determinations were performed in duplicate.

UV Absorption of Egg Fat. The intensity of the absorption at the most characteristic maxima of fatty acid oxidation products (232, 270, and 303 nm) (Galanos *et al.*, 1968; Gunstone, 1986; Uzzan, 1956; Wolff, 1954, 1968) was determined in the lipid fraction of egg samples, which was obtained according to the method proposed by Folch *et al.* (1957).

Powdered egg (0.80 g) of thawed egg (5.4 g) was extracted with 15 mL of chloroform/methanol (2:1 v/v) for 30 min. The residue was re-extracted with 10 mL of the same solvent mixture for 20 min, and the two organic phases were filtered into a screw-capped tube. Five milliliters of the same mixture was used to rinse the solid residue and was added to the tube. Five milliliters of distilled water was added finally to the tube, and the whole was shaken and then centrifuged at 2200 rpm for 20 min. The chloroformic phase was filtered through anhydrous sodium sulfate and then concentrated to 1 mL, by a vacuum rotatory evaporator at 35 °C. The rest of the solvent was removed by a slight nitrogen stream and keeping the flask in a vacuum desiccator (750 mmHg) all night.

Absorption intensities at 232, 270, and 303 nm were determined according to the method proposed by Wolff (1968). In a 10 mL volumetric flask, 40 mg of fat extracted from powdered egg (or 60 mg in the case of thawed egg) was dissolved in cyclohexane. Specific absorbances (K_{232}, K_{270}, and K_{303}) were determined by applying the formula $K_\lambda = E^{1\%}_{1cm\lambda} = A_\lambda/C\ W$, where A_λ is the absorbance registered, C is the concentration of the cyclohexanic solution expressed as g of fat/100 mL, and W is the width of the spectrophotometer cell in cm. When the absorbance values at these wavelengths did not fall between 0.2 and 0.8, dilutions were made. For all samples at 232 nm a 3–10 dilution was necessary. Determinations of specific absorbances were performed in triplicate.

Color Determination. The AOAC method (958.05, AOAC, 1990) with a few modifications was used to evaluate the color loss during the spray-drying process; this measures the whole carotenoid content. Thawed egg (3.6 g) or egg powder (1.4 g) was weighed and homogenized with 2.5 mL of acetone to a paste; 20 mL of acetone was then added, and the blend was subjected to magnetic stirring for 5 min. After filtration through Whatman No. 4 paper, the solution was diluted with acetone in a 25 mL volumetric flask. The intensity of the absorption at 440 nm was measured in this solution. All determinations were performed in duplicate. Calculation of carotenoid content, expressed as micrograms of β-carotene per gram of total solids, was performed by applying a calibration curve. The curve was constructed by preparing five solutions of increasing β-carotene concentration between 0.27 and 2.72 μg/mL acetone, to obtain absorbance values between 0.0458 and 1.0000, as recommended by the AOAC method. Readings of these five solutions were performed in quintuplicate. The equation obtained for the calibration curve was $y = 0.2244x + 0.0021$, where y is the absorbance and x the concentration in micrograms of β-carotene per milliliter. The precision of the method was also checked by applying the determination to 10 aliquots of the same sample, and the results showed a CV = 2.0%.

Maillard Browning Determination. The development of the Maillard reaction in powdered egg samples was measured following the method proposed by Tsai *et al.* (1991) with a few modifications: 0.8 g of sample was homogenized by magnetic stirring, for 10 min, in 10 mL of a 10% w/v solution of trichloroacetic acid and then filtered through a Whatman No. 42 paper filter; the liquid extract was recovered, as well as the portions of the acid solution used to rinse the solid residue, in a 10 mL volumetric flask, and then diluted to this volume; finally, the intensity of absorption at 420 nm was measured in a spectrophotometer Shimadzu (Kyoto, Japan). All determinations were performed in duplicate. The precision of the method was determined by applying the method to 10 aliquots of the same sample, and the results showed a CV = 2.4%.

Cholesterol Determination. This was carried out following the method proposed by Guardiola *et al.* (1994).

Oxysterol Determination. The OS determination was performed following the method proposed in a former study (Guardiola *et al.*, 1995). The method consists of the lipid extraction, according to the method proposed by Folch *et al.* (1957), from 0.65 g of powdered egg (or 4 g of liquid egg) with the addition of 25 μg of the internal standard 19-HC. The lipid extract was subjected to cold saponification in the following conditions: 10 mL of N KOH solution in methanol was added to the amber flask containing the lipid extract, with gentle agitation to obtain a homogeneous phase; the mixture was then kept at room temperature for 20 h to complete the saponification; the blend was then transferred to a screw-cap tube, diluted with 10 mL of distilled water, and extracted three times with 10 mL of diethyl ether; the whole organic extract was then washed in a separating funnel, first in 5 mL of 0.5 N KOH aqueous solution, and then in two fractions of 5 mL of distilled water, and finally filtered through anhydrous sodium sulfate; after removal of solvent, the nonsaponifiable extract was redissolved in 5 mL of hexane and applied quantitatively to a silica cartridge (Sep-Pak), previously equilibrated with 5 mL of hexane; the cartridge was then eluted with solvent mixtures of increasing polarity (5 mL of hexane, 10 mL of hexane/diethyl ether, 95:5 v/v; 30 mL of hexane/diethyl ether, 90:10 v/v; 10 mL of hexane/diethyl ether, 80:20 v/v; and 10 mL of acetone/methanol, 60:20 v/v); the last fraction, which contained the OS, was recovered in a round-bottom flask and concentrated to 1 mL, using a rotatory vacuum evaporator; this solution of OS was transferred quantitatively with diethyl ether to a glass tube (10 × 75 mm);

Table 1. Mean Contents of Oxysterols for Frozen Eggs and Powdered Eggs Obtained at Three Temperatures of Spray-Drying (Parts per Million in Solids)

		powdered eggs ($n = 6$)		
oxysterol	frozen eggs ($n = 6$)	T_A[a]	T_B	T_C
α-CE	0.76	7.60*[b]	8.56**	10.71*
7β-HC	0.88	11.28**	13.01**	17.39**
CT	4.10	7.13**	7.89**	8.76*
7-KC	3.95	23.66***	22.97***	30.58*
25-HC	0.65	1.19**	1.21**	1.47*
total OS	10.33	50.85***	53.64***	68.91**

[a] T = temperatures of spray-drying (inlet–outlet temperatures): T_A (180–120 °C); T_B (193–128 °C); T_C (231–142 °C). [b] Significance levels of the differences between powdered and frozen egg samples, coming from *a priori* contrasts for repeated mesures (α = 0.05) (*$P \leq 0.01$, **$P \leq 0.001$, ***$P \leq 0.0001$).

removal of solvent was completed using a slight nitrogen stream, at 25 °C, and finally in a vacuum desiccator at 10 mmHg for 1 h; afterward, the final residue obtained was redissolved in 50 μL of anhydrous pyridine; 50 μL of Sylon BTZ was then added, and the mixture was kept at room temperature for 20 min to complete the silanization reaction, before injection to the column. The silyl derivatives are stable for several days at −20 °C (Park and Addis, 1985). All determinations and injections were performed in duplicate.

Gas chromatography was performed using a Perkin-Elmer chromatograph Model Autosystem, equipped with a flame ionization detector and fused silica capillary column (25 m × 0.25 mm i.d.), with a film thickness of 0.13 μm stationary phase of methyl silicone (CP-Sil 5 CB) from Chrompack (Middelburg, The Netherlands). Helium was used as carrier gas, and the chromatographic conditions were as follows: oven temperature programmed from 210 to 264 °C at 2 °C/min, from 264 to 290 °C at 5 °C/min, and held for 80 min at 290 °C; injector temperature, 290 °C; detector temperature, 350 °C; split ratio, 1:30; inlet pressure, 15 psi; sample volume injected, 2 μL. Identification of OS was accomplished following the procedure described by Guardiola *et al.* (1995), which includes cochromatography and mass spectroscopy.

RESULTS AND DISCUSSION

Oxysterol Formation during the Spray-Drying Process. Table 1 shows the results of OS contents in the frozen egg samples and in the three powdered egg samples obtained at the three spray-drying temperature assayed (T_A, T_B, and T_C). The ANOVA for repeated measures applied to these results shows significant differences between the mean values of all OS in the four types of sample (α-CE, $P < 0.0001$; 7β-HC, $P < 0.0001$; CT, $P < 0.0001$; 7-KC, $P < 0.0001$; 25-HC, $P < 0.0001$; and total OS, $P < 0.0001$). The further application of *a priori* contrasts for repeated measures (α = 0.05) showed that these differences exist between the group of frozen eggs and all groups of dried eggs (Table 1).

From these results it can be concluded that the levels of OS in the three dried egg samples obtained by spray-drying are clearly higher than the OS levels in the frozen egg samples, especially for 7β-HC and 7-KC.

Effect of Spray-Drying Temperature on OS Formation. To study the differences existing in the OS formation among the three temperatures of spray-drying applied, the variable ΔOS was defined as the subtraction of the OS contents in the frozen egg from the contents in each one of the three powdered eggs (A, B, and C). Mean values of this variable for each OS and for the total OS are given in Table 2. The analysis of variance applied to these data shows significant differences for α-CE ($P = 0.0242$), 7β-HC ($P = 0.0081$), 25-HC ($P = 0.0244$), and total OS ($P = 0.0161$) among the three temperatures. For 7-KC almost significant differences are found ($P = 0.0836$). No significant differences were found for CT. In all cases that show significant differences, *a priori* contrasts (α = 0.05) were applied to determine whether mean values of the variable ΔOS differ between T_B and T_A (contrast expressed as $\mu_A - \mu_B$), between T_C and T_A (contrast $\mu_A - \mu_C$), between T_C and T_B (contrast $\mu_B - \mu_C$), and between T_C and the group of T_A and T_B (contrast $[(\mu_A + \mu_B)/2] - \mu_C$). Table 3 shows the significance level of these contrasts and the confidence intervals. According to these results, the following conclusions may be reached: OS formation is not higher at the temperature

Table 2. Results of Variables Studied[a]

S[b]	cholesterol content	T[c]	Δα-CE	Δ7β-HC	ΔCT	Δ7-KC	Δ25-HC	Δtotal OS	ΔK_{232}	ΔK_{270}	ΔK_{303}	color loss	MBI
1	17.34	T_A	6.54	9.62	2.59	18.63	0.47	37.84	0.45	0.16	0.13	12.55	0.025
		T_B	4.79	7.67	3.36	14.74	0.60	31.16	0.33	0.19	0.13	13.53	0.028
		T_C	6.22	10.46	2.73	15.54	0.50	35.43	0.49	0.16	0.13	12.82	0.033
2	16.13	T_A	4.83	8.02	4.15	16.94	0.37	34.30	3.92	0.76	0.42	14.22	0.024
		T_B	6.63	9.41	2.80	17.95	0.49	37.27	1.87	0.67	0.41	16.19	0.033
		T_C	8.85	16.83	2.76	39.41	0.50	68.34	4.00	1.17	0.88	19.73	0.051
3	16.42	T_A	11.72	15.65	4.28	27.19	0.75	59.60	5.58	1.25	0.75	18.70	0.040
		T_B	12.32	17.02	4.78	22.27	0.81	57.20	5.59	1.35	0.88	19.59	0.050
		T_C	18.63	24.68	9.11	31.07	1.26	84.74	5.35	1.50	1.03	22.76	0.070
4	16.27	T_A	5.86	9.97	2.10	20.02	0.34	38.30	1.88	0.49	0.27	14.72	0.026
		T_B	5.93	11.70	2.71	16.82	0.37	37.53	0.46	0.53	0.35	15.41	0.026
		T_C	6.97	14.86	5.37	19.08	1.05	47.32	1.91	0.46	0.22	20.78	0.027
5	16.51	T_A	6.56	10.90	3.34	18.20	0.65	39.66	1.07	0.78	0.51	17.18	0.032
		T_B	7.90	12.97	4.51	18.43	0.56	44.37	0.71	0.75	0.46	17.91	0.033
		T_C	7.74	11.26	4.41	19.30	0.87	43.57	0.54	0.64	0.29	15.94	0.032
6	16.48	T_A	5.54	8.23	1.72	17.28	0.66	33.44	ND[d]	ND	ND	ND	ND
		T_B	9.23	14.01	4.62	23.89	0.60	52.35	ND	ND	ND	ND	ND
		T_C	11.34	20.99	3.59	35.40	0.78	72.10	ND	ND	ND	ND	ND
$\bar{X}$[e]	16.52	T_A	6.84	10.40	3.03	19.71	0.54	40.52	2.58	0.69	0.42	15.47	0.029
		T_B	7.80	12.13	3.79	19.02	0.57	43.31	1.78	0.70	0.45	16.53	0.034
		T_C	9.96	16.51	4.66	26.63	0.83	58.58	2.46	0.79	0.51	18.41	0.043

[a] Cholesterol content in frozen egg samples (mg/g of solids); ΔOS (ppm in solids); ΔK_x (increase of specific absorbance); color loss (μg of β-carotene/g of solids); MBI (Maillard browning intensity, absorbance at 420 nm/g of solids). [b] Starting frozen egg sample. [c] Temperatures of spray-drying (inlet–outlet temperatures): T_A (180–120 °C); T_B (193–128 °C); T_C (231–142 °C). [d] Not determined. [e] Mean value (n = 6 or 5).

Table 3. Significance Levels and Confidence Intervals (95%) of *a Priori* Contrasts Comparing ΔOS Means (Parts per Million in Solids) at Different Temperature Conditions

	contrasts (Φ)			
oxysterol	$\mu_A - \mu_B$[a,b]	$\mu_A - \mu_C$	$\mu_B - \mu_C$	$[(\mu_A + \mu_B)/2] - \mu_C$
α-CE	NS[c]	$P = 0.0464$	AS[d]	$P = 0.0439$
		0.07–6.16	$P = 0.0622$	0.11–5.17
7β-HC	NS	$P = 0.0292$	$P = 0.0334$	$P = 0.0278$
		0.92–11.31	0.51–8.25	0.85–9.64
25-HC	NS	$P = 0.0457$	AS	AS
		0.01–0.56	$P = 0.0805$	$P = 0.0587$
total OS	NS	$P = 0.0473$	$P = 0.0336$	$P = 0.0362$
		0.31–35.81	1.76–28.80	1.59–31.74

[a] μ_A= mean of variable ΔOS for conditions T_A (this variable was defined as oxysterol content in the dried egg obtained at conditions T_A − oxysterol content in the starting frozen egg). μ_B = mean of variable ΔOS for conditions T_B (this variable was defined as oxysterol content in the dried egg obtained at conditions T_B − oxysterol content in the starting frozen egg). μ_C = mean of variable ΔOS for conditions T_C (this variable was defined as oxysterol content in the dried egg obtained at conditions T_C − oxysterol content in the starting frozen egg). [b] Contrast that compares the ΔOS mean for conditions T_A with mean values for conditions T_B. [c] Nonsignificant. [d] Almost significant ($P \leq 0.10$).

conditions T_B with respect to conditions T_A; formation is significantly higher at conditions T_C with respect to conditions T_A for α-CE, 7β-HC, 25-HC, and total OS; formation is significantly higher at conditions T_C with respect to conditions T_B for 7β-HC and total OS; formation is significantly higher at conditions T_C with respect to conditions T_A and T_B for α-CE, 7β-HC, and total OS. The main conclusion is that at the lowest temperatures tested (T_A and T_B) OS formation is clearly lower and there is a critical point between T_B and T_C at which OS formation significantly increases.

Cholesterol Determination. Cholesterol was determined in the starting frozen egg samples to search for possible relationships between the cholesterol content of the egg and the formation of OS, as suggested by other authors (Morgan and Armstrong, 1987). As can be seen in Table 2, the homogeneity of cholesterol content in the starting frozen eggs is not translated into OS formation homogeneity in the powdered eggs, which means that other composition factors influence this formation.

Moisture. The mean value of moisture found in frozen egg samples was 23.83%. Mean values in dried egg samples were 1.80, 1.91, and 2.15%, respectively, for spray-drying temperatures A, B, and C. The analysis of variance shows that there is no significant difference in moisture for the dried egg samples related to the temperature of spray-drying.

UV Absorption (K_{232}, K_{270}, and K_{303}). Table 2 shows the results corresponding to the increase in specific absorbance at the three wavelengths (232, 270, and 303 nm) calculated by subtraction of starting frozen egg specific absorbance from dried egg specific absorbance. These increases are symbolized by ΔK_{232}, ΔK_{270}, and ΔK_{303}.

Table 2 shows some differences in the ΔK_x mean values as a function of the spray-drying temperature, but the application of analysis of variance ($\alpha = 0.05$) indicates that these differences are not significant in any case.

Color Determination. The parameter color loss, expressed as micrograms of β-carotene per gram of solids, was obtained by the subtraction of color measure in the dried egg from the measure corresponding to starting frozen egg. This parameter represents the destruction of carotenoids induced by the spray-drying process (Table 2). There is increasing loss of color with increasing spray-drying temperature, but the analysis of variance indicates that these differences are not statistically significant.

Maillard Browning Intensity. Table 2 shows the results obtained for the determination of the Maillard browning intensity in the dried egg samples measured as absorbance at 420 nm per gram of solids. Maillard browning intensity increases in relation to the spray-drying temperature, but the anlysis of variance reveals that there is no significant difference between the three kinds of dried egg.

Correlations between OS Formation and Other Quality Control Parameters. A correlation study (Spearman test, $\alpha = 0.05$) was performed on the results obtained for the three kinds of dried egg, among the following parameters: Δα-CE, Δ7β-HC, ΔCT, Δ7-KC, Δ25-HC, Δtotal OS, ΔK_{232}, ΔK_{270}, ΔK_{303}, color loss, and Maillard browning intensity. The results of this study are given in Table 4. Linear correlations were found between the formation of OS during the spray-drying process and the color loss and the increase in specific absorbance at 232, 270, and 303 nm. This finding seems

Table 4. Spearman Correlation Coefficients (r_s) and Significance Levels[a]

Δα-CE	Δ7β-HC	ΔCT	Δ7-KC	Δ25-HC	Δtotal OS	ΔK_{232}	ΔK_{270}	ΔK_{303}	color loss	MBI	
1.0000[b]	0.6751	0.4929	0.5179	0.5321	0.6500	0.3321	0.4393	0.4893	0.6500	0.5666	Δα-CE
	$P = 0.0139$[c]	$P = 0.0652$	$P = 0.0527$	$P = 0.0465$	$P = 0.0150$	NS[d]	NS	$P = 0.0671$	$P = 0.0150$	$P = 0.0340$	
	1.0000	0.5393	0.7500	0.6036	0.9250	0.6393	0.6500	0.6821	0.8464	0.6756	Δ7β-HC
		$P = 0.0436$	$P = 0.0050$	$P = 0.0239$	$P = 0.0005$	$P = 0.0168$	$P = 0.0150$	$P = 0.0107$	$P = 0.0015$	$P = 0.0115$	
		1.0000	0.3250	0.8536	0.5214	0.4964	0.5357	0.4714	0.6893	0.4290	ΔCT
			NS	$P = 0.0014$	$P = 0.0511$	$P = 0.0632$	$P = 0.0450$	$P = 0.0777$	$P = 0.0099$	NS	
			1.0000	0.4321	0.9107	0.7321	0.6071	0.6107	0.7000	0.5433	Δ7-KC
				NS	$P = 0.0007$	$P = 0.0062$	$P = 0.0231$	$P = 0.0223$	$P = 0.0088$	$P = 0.0421$	
				1.0000	0.6250	0.3750	0.4250	0.3714	0.6786	0.5630	Δ25-HC
					$P = 0.0194$	NS	NS	NS	$P = 0.1111$	$P = 0.0352$	
					1.0000	0.6893	0.6679	0.6929	0.8679	0.6506	Δtotal OS
						$P = 0.0099$	$P = 0.0125$	$P = 0.0095$	$P = 0.0012$	$P = 0.0149$	
						1.0000	0.8107	0.7679	0.7393	0.5362	ΔK_{232}
							$P = 0.0024$	$P = 0.0041$	$P = 0.0057$	$P = 0.0448$	
							1.0000	0.9821	0.7321	0.9488	ΔK_{270}
								$P = 0.0002$	$P = 0.0062$	$P = 0.0152$	
								1.0000	0.7607	0.6720	ΔK_{303}
									$P = 0.0044$	$P = 0.0119$	
									1.0000	0.6595	color loss
										$P = 0.0136$	
										1.0000	MBI

[a] See Table 2 for abbreviations. [b] Spearman correlation coefficient ($n = 15$). [c] Significance level. [d] Nonsignificant.

to confirm that the formation of oxysterols in dried egg parallels the other lipid oxidative processes, but the fact that OS formation showed the best correlation with color loss could be related to the fact that cholesterol and carotenoids present antioxidant properties. This capacity of cholesterol has been reported recently *in vivo* and *in vitro* by some authors (Blackwelder and Pike, 1990; Jain and Shohet, 1981; Smith, 1990, 1991; Szebeni and Toth, 1986). A linear correlation was also found between OS formation and Maillard browning intensity (420 nm).

NOMENCLATURE

Cholestanetriol (CT) (5α-cholestane-3β,5,6β-triol); cholesterol (cholest-5-en-3β-ol); cholesterol 5α,6α-epoxide (α-CE) (5,6α-epoxy-5α-cholestan-3β-ol); 7β-hydroxycholesterol (7β-HC) (cholest-5-ene-3β,7β-diol); 19-hydroxycholesterol (19-HC) (cholest-5-ene-3β,19-diol); 25-hydroxycholesterol (25-HC) (cholest-5-ene-3β,25-diol); 7-ketocholesterol (7-KC) (3β-hydroxycholest-5-en-7-one).

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