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Oat Fiber As a Carrier for Curcuminoids

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ABSTRACT: The curcuminoid-carrying potential of oat fiber was examined as a potential route to overcome the low aqueous solubility of curcuminoids. Aqueous dispersions of oat fiber were mixed with curcuminoids solubilized in ethanol to obtain curcuminoids−oat fiber (1% w/w) dispersions in aqueous ethanol (2% v/v). Centrifugation of the curcuminoids−oat fiber dispersions resulted in a supernatant (95.3% w/w: 0.11% w/w protein, 0.17% w/w β-glucan) and precipitate (4.74% w/w: 0.18% w/w protein, 0.11% w/w β-glucan) with the curcuminoids being almost equally partitioned into both fractions. Curcuminoids solubility in the supernatant was markedly greater than that in aqueous ethanol and water. The curcuminoids were in the amorphous state in the precipitated fraction and were more stable to degradation than the curcuminoids in the supernatant. These studies show the potential of oat fiber as a carrier for curcuminoids into functional foods.

KEYWORDS: *curcumin, solubility, oat fiber, beta-glucan, carrier*

INTRODUCTION

Foods rich in polyphenols are an important source of dietary antioxidants considered important for prevention of cancer and the alleviation of diabetes, cardiovascular diseases, neurodegenerative diseases, and osteoporosis.[1−4] The bioavailability of polyphenols is affected by many factors including interactions with the food matrix and its ingredients, the gut transit time, and colonic microflora.[5] Encapsulation of polyphenolic compounds has been suggested as a possible strategy to address issues related to their poor bioavailability.[6,7]

Curcumin, (1,7-bis(4-hydroxy-3-methoxyphenyl)-1,6-heptadience-3,5-dione), the major component in turmeric roots (*Curcuma longa* L.) has been traditionally used for medicinal purposes.[8] There is increasing interest in curcumin because of its purported antioxidative, antiatherosclerotic, and anti-inflammatory properties and its potential role in prevention of diabetes, Alzheimer's, multiple sclerosis, cardiovascular disease, lung fibrosis, arthritis, and inflammatory bowel disease.[9] However, the low solubility of curcumin in aqueous solutions and its poor bioavailability limits its application.[10] Approaches to overcome the low solubility of curcumin in an aqueous environment include the complexation of curcumin with food proteins[11−13] or encapsulation of curcumin in starch.[14] Recently, it was reported that the bioavailability of curcumin was improved by formulating curcumin with fenugreek-derived soluble dietary fiber.[15]

Oats contain protein, fiber, and fat in amounts that are generally higher than other cereals. Fractionation of the oat grain enables the preparation of a range of ingredients such as oat fiber concentrates and oat protein isolates. Oat fiber is a rich source of soluble fiber such as β-glucan. This makes it attractive as a functional food ingredient and as a carrier for bioactives; however, its application as a carrier material for curcuminoids is unknown. In this work, we examined the potential of oat fiber as a carrier for curcuminoids for functional food applications. In characterizing its potential as a carrier for curcumin, we also examined the partitioning of curcuminoids between the soluble and insoluble fractions of curcuminoid−oat fiber dispersions.

MATERIALS AND METHODS

Materials. A powdered turmeric extract (Biocurcumin, BCM-95CG, total curcuminoids complex, purity: 95.7%) was a gift from Arjuna Natural Extracts Ltd. (Kerala, India). Previous analysis in our laboratory indicated that this material consists of 70 ± 0.5% curcumin, 15.0 ± 0.2% demethoxycurcumin, and 1.8% bisdemethoxycurcumin.[16] Oat fiber was provided by CreaNutrition (Zug, Switzerland). Oat β-glucan (>95%) was purchased from Megazyme (Bray, Ireland). Ethanol (EtOH, 100%) was obtained from Sigma-Aldrich (Sydney, NSW, Australia).

Gross Composition. The amounts of protein, β-glucan, and total solids in the oat fiber and in the supernatant and precipitated fractions obtained upon centrifugation of oat dispersions were determined. The lipid content of the oat fiber was also estimated. Protein content was analyzed using a LECO FP-2000 Nitrogen Analyzer (LECO Australia Pty Ltd., Castle Hill, NSW, Australia). Quantification of β-glucan, lipid, and total solids was carried out based on the AOAC Official Method 995.16,[17] Australian Standard method AS 2300.1.3,[18] and AOAC Official Method 990.20,[19] respectively. The oat fiber contained 28.2 ± 0.9 (% w/w) protein, 26.0 ± 0.8 (% w/w) β-glucan, 5.6 ± 0.6 (% w/w) lipid, 6.6 ± 0.1 (% w/w) moisture, and other components (nonmeasured components that include carbohydrates and other dietary fiber), 33.5 ± 0.5 (% w/w).

Solubility of Curcuminoids. *Solubility in Aqueous Ethanol.* A dispersion of curcuminoids (25.8 μg/mL) in 2% v/v EtOH was prepared by diluting a stock solution of curcuminoids (1280 μg/mL) in 100% EtOH with water.

Solubility in Oat Fiber Dispersions. Curcuminoid (0−368 μg/mL)−oat fiber (1% total solid (TS), w/w) dispersions were prepared by dispersing the required volume of curcuminoids (dissolved in 100% EtOH) into the oat fiber dispersion (1% TS, w/w) in water. The EtOH concentration in the final dispersions was 2% v/v. The

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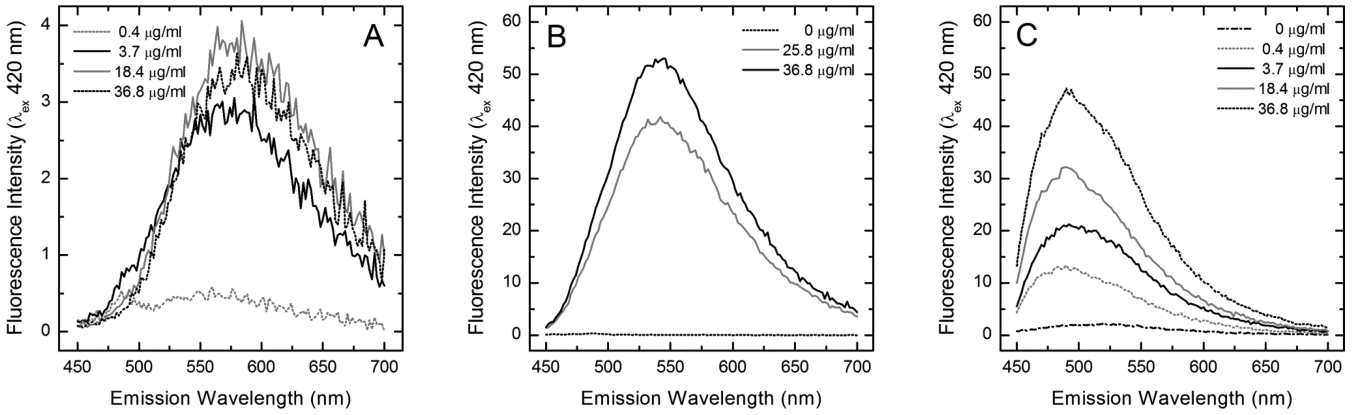

Figure 1. Fluorescence spectra of curcuminoids in (A) 2% (v/v) EtOH; (B) a dispersion of β-glucan (0.28% TS, w/w) in 2% (v/v) EtOH; and (C) a dispersion of oat fiber (1% TS, w/w) in 2% (v/v) EtOH.

dispersions were sonicated in an ultrasonic bath (Unisonic Australia Pty, Brookvale, NSW, Australia) at 20 kHz and 30 °C for 10 min followed by homogenization at 13 500 rpm for 10 min with an Ultra Turax T25 homogenizer (Crown Scientific Pty, Murrarie, QLD, Australia).

Preparation of Stock Solution and Dispersions for Partitioning and Binding Experiments. Freshly prepared dispersions (pH 6.8 ± 0.1) of curcuminoids (25.8 μg/mL) with oat fiber (1% TS, w/w) were used for the partitioning experiments. The curcuminoids were solubilized in 100% EtOH prior to addition to the oat fiber dispersion. The EtOH concentration in the final dispersions was 2% v/v.

To separate the soluble from insoluble fractions of the dispersions, samples were ultracentrifuged (20 400 g, 20 min, 22 °C) to obtain a soluble fraction (supernatant) and an insoluble fraction (precipitate). Each fraction was weighed. The supernatant and precipitate compositions were analyzed separately for total solids, protein, and β-glucan content. Curcuminoids were also extracted from the supernatant by mixing 5 g of the supernatant with 100% EtOH to obtain an extract in 80% (v/v) EtOH. The dispersion was stirred for 20 min and then centrifuged at 12 100 g at 22 °C for 20 min. A second extraction was carried out, and the supernatants from the first and second extractions were combined and used for fluorescence measurements. For the extraction of curcuminoids in the precipitate, 0.2 g of the precipitated fraction was mixed with 1.6 mL of 80% v/v EtOH. The extraction was repeated twice with 1.6 mL of 80% v/v EtOH. After each extraction, the dispersion was stirred for 45 min and centrifuged at 12 100 g and 22 °C for 20 min, and the supernatant was collected from each extraction and combined for analysis. The concentration of curcuminoids from the extracts was analyzed by fluorescence spectroscopy. The curcuminoid concentration was quantified using a calibration curve of curcuminoids in 80% v/v EtOH at concentrations of 0.4−5.5 μg/mL. Spiking experiments with a known amount of curcuminoids were also carried out to confirm the recovery of curcuminoids from each fraction. The results showed a recovery of ∼93%.

Preparation of Curcuminoids−β-Glucan Dispersion in 2% EtOH. β-glucan (84 mg) was dispersed in 29.08 mL of Milli-Q water, and an aliquot of 0.6 mL of the curcuminoid stock solution (1280 μg/mL) in pure EtOH was added to this dispersion to obtain the final mixtures of curcuminoid (25.8 μg/mL)−β-glucan (0.28% TS, w/w) in 2% v/v EtOH. A 0.28% w/w β-glucan concentration was equivalent to the amount of β-glucan present in a 1% w/w oat fiber dispersions used to examine the interaction of oat fiber with curcuminoids in this work. The dispersions were sonicated, homogenized, and centrifuged as previously described. The pH value of the mixtures was 7.0. The amount of curcuminoids in the supernatant was analyzed by fluorescence measurements after extraction.

Fluorescence Measurements. The fluorescence spectra of curcuminoids, oat fiber dispersion (1% TS w/w), curcuminoid−oat fiber dispersions (1% TS, w/w), and curcuminoid−β-glucan dispersions (0.28% TS, w/w), all in aqueous EtOH (2% v/v), were measured using a spectrofluorometer (Varioskan Flash microplate reader, Thermo Fisher Scientific Inc., Waltham, MA, USA). Samples (350 μL) were loaded into a 96-well microplate (OptiPlate-96, PerkinElmer, Santa Clara, CA, USA). The fluorescence emission spectra were recorded from 450−700 nm at a fixed excitation wavelength (λ_{ex}) of 420 nm.[11,12]

To probe the quenching of the intrinsic fluorescence of proteins in oat fiber dispersions, emission spectra were recorded from 315−600 nm at an excitation wavelength (λ_{ex}) of 280 nm.[20]

X-ray Diffraction. The powdered curcumin (1 g) and the precipitate (1.36 g) obtained after centrifugation of the curcuminoid (25.8 μg/mL)−oat fiber (1% TS, w/w) dispersions in aqueous EtOH (2% v/v) were analyzed by an X-ray (D8 Advance) diffractometer (Bruker AXS Inc., Madison, WI, USA) with Cu Kα radiation. The machine was equipped with backgroundless sample holders. The X-ray diffraction (XRD) scanning was performed at a rate of 0.02 degrees step size and 5 s per step with the scanned angle set from $10° \leq 2\theta \geq 70$. Measurements were performed at a voltage of 40 kV and 30 mA.

Storage Stability of Curcuminoids. The storage stability of curcuminoids in the curcuminoids (25.8 μg/mL)−oat fiber (1% TS, w/w) dispersions in 2% (v/v) EtOH and the supernatant fraction obtained upon centrifugation at 20 400 g (Beckman J2-MC, Ramsey, MN, USA) for 20 min at 22 °C was determined. The curcuminoids content in the precipitated fraction was obtained by difference. Sodium azide was added to all samples (0.02% w/w) to prevent microbial spoilage. Samples (5 g) were placed in glass vials and were stored at 25 °C for 11 days. Samples were taken at intervals for the analysis of curcuminoids. Curcuminoids were extracted using EtOH, and the curcuminoid concentration was estimated using fluorescence spectroscopy as previously outlined.

RESULTS AND DISCUSSION

Fluorescence Measurements. *Fluorescence of Curcuminoids in 2% v/v EtOH.* The florescence intensity of curcuminoid (0−36.8 μg/mL) in 2% (v/v) EtOH is shown in Figure 1A. The maximum emission wavelength was at 566 nm. The fluorescence intensity of samples containing 3.7, 18.4, and 36.8 μg/mL were 2.7, 4.0, and 3.6, respectively. One factor that may contribute to the nonlinear increase in fluorescence intensity with increased curcuminoids concentrations from 3.7−18.4 μg/mL is the supersaturation of curcumin at high concentrations. In addition, with increasing curcuminoid concentration in 2% v/v EtOH, there is likely to be self-quenching of curcuminoids. Self-quenching is particularly prevalent at higher concentrations. Self-quenching of polyphenols compounds has been previously observed.[21]

Fluorescence of Curcuminoids in the Presence of Pure β-Glucan in 2% v/v EtOH. The fluorescence spectra of

curcuminoids in the presence of pure β-glucan (0.28% TS, w/w) are shown in Figure 1B. There was a blue shift in the position of the maxima when curcuminoids were dispersed in the presence of β-glucan in 2% v/v EtOH (542 nm) compared to curcuminoids in 2% v/v EtOH alone (566 nm). At an equivalent concentration of added curcuminoid (36.8 μg/mL), the fluorescent intensity of the curcuminoid−β-glucan dispersions in 2% v/v EtOH was greater than that in 2% v/v EtOH alone (Figure 1A,B). These observations may be interpreted as an increased solubility of curcuminoids due to binding to the β-glucan, possibly due to hydrogen bonding and complexation of the phenolic groups of curcumin to β-glucan.[22]

Fluorescence of Curcuminoids in the Presence of Oat Fiber in 2% v/v EtOH. In curcuminoids−oat fiber (1% TS, w/w) dispersions containing 2% v/v EtOH, a blue shift in the wavelength of maximum emission was observed from about 566 nm for curcuminoids in 2% v/v EtOH (Figure 1A) to about 490 nm in oat fiber dispersions with 2% EtOH (Figure 1C). This blue shift in the emission wavelength is consistent with a transfer of the curcuminoids into a less polar microenvironment. At corresponding levels of added curcuminoids (36.8 μg/mL), the fluorescence intensity of the curcuminoids in the presence of oat fiber in 2% v/v EtOH was approximately 47, whereas it was only approximately 3.6 in 2% v/v EtOH (Figure 1a,c). Blue shifts in the emission spectra of curcuminoids have been observed in mixtures containing casein micelles,[11] hydrophobically modified starch,[14] β-casein,[23] and β-lactoglobulin,[24] and for liposomal curcumin preparations,[25] and are consistent with the transfer of curcuminoids into a less polar environment. It was not possible to ascribe the relative binding affinities of the various curcuminoids to components of the oat fiber from the fluorescence spectra obtained in this study.

Fluorescence of Proteins in Curcuminoids−Oat Fiber Mixtures. The quenching of the intrinsic fluorescence of proteins within the curcuminoids−oat fiber mixture and the blue shift in the wavelength of maximum emission (Figure 2) are evidence of binding of the curcuminoids to protein. An increase in the curcuminoid concentration from 0−44.2 μg/mL resulted in a progressive increase in quenching, but there was no further increase when the concentration was raised to 55.3 μg/mL (Figure 2). Quenching has been observed for binding of curcuminoids to various types of proteins including milk proteins,[12] soy protein,[13] and plasma proteins.[26]

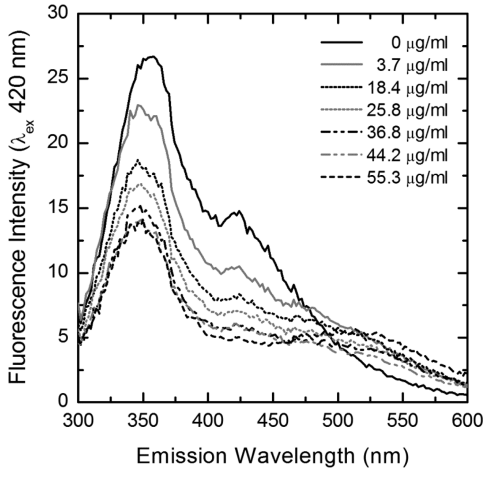

Figure 2. Protein fluorescence spectra of curcuminoid−oat fiber (1% TS, w/w) dispersions in 2% (v/v) EtOH at λ_{ex} = 280 nm.

Partitioning of Oat Fiber Components and Curcuminoids between Soluble and Insoluble Fractions upon Centrifugation. *Partitioning of Oat Fiber Components.* The partitioning of oat fiber components and curcuminoids in the supernatant and precipitated fractions of curcuminoid−oat fiber dispersions was examined to estimate the distribution of curcuminoids in the soluble and insoluble fraction. For these experiments, we used 25.8 μg/mL curcuminoids in a 1% TS (w/w) oat fiber dispersion in 2% v/v EtOH.

Upon centrifugation of the oat fiber dispersion (1% TS, w/w) in 2% v/v EtOH, a supernatant (soluble) fraction (95.3% w/w, 0.28% TS) and a precipitated (4.7% w/w, 0.73% TS) fraction were obtained (Table 1). Of the total protein in the oat fiber dispersion, 38% partitioned into the supernatant, while 62% partitioned into the precipitate. Most of the β-glucan (61% of the total β-glucan) partitioned into the supernatant, with 39% found in the precipitated fraction (Table 1). Both soluble and insoluble proteins and β-glucans present in unprocessed oats are expected to be present in the oat fiber ingredient used in our experiments. The solubility of the proteins and β-glucan components and their distribution between the soluble and insoluble phases will depend on the isolation methods used to extract and process the oat fiber ingredient. Oat proteins comprise globulins, albumins, prolamins, and glutenins, and of these, the albumins are the most water-soluble proteins.[27] The insoluble β-glucans have lower molecular mass than the soluble β-glucan but remain in the insoluble fiber fraction because of entanglement with arabinoxylan.[28]

Partitioning of Curcuminoids. The curcuminoids were approximately equally partitioned between the supernatant and precipitated fractions obtained upon centrifugation of the curcuminoid (25.8 μg/mL)−oat fiber (1% TS, w/w) dispersion (pH 6.8 ± 0.1) in aqueous 2% v/v EtOH. The supernatant contained 38.6 ± 2.7%, and the precipitated fraction contained 41.1 ± 2.15% of the total added curcuminoids. Thus, the total amount recovered from both the supernatant and precipitated fractions accounted for approximately 79.7% of the total curcuminoids originally added (Table 1). Analysis of the washings from the preparation apparatus (i.e., sample container and the probe used for homogenization) recovered an additional 13.4 ± 0.7% of the total added curcuminoids, which amounts to a total curcuminoids recovery of 93.1%.

Solubility of Curcuminoids. *Solubility in 2% v/v EtOH.* Measurement of the supernatant fractions obtained upon centrifugation of 25.8 μg/mL curcuminoids dispersed in 2% v/v EtOH without oat fiber showed that the highest concentration of curcuminoids in the supernatant was 4.1 μg/mL. This result showed that the solubility of curcuminoids in aqueous EtOH (2% v/v) exceeds that of the reported solubility of curcumin in aqueous media (11 ng/mL, pH 5).[29]

Solubility in the Presence of Oat Fiber (1% TS, w/w) in 2% v/v EtOH. The solubility of the curcuminoids in the oat fiber dispersion was taken as the concentration of curcuminoids in the supernatant. An increase in the concentration of curcuminoids in the oat fiber dispersion from 0 to ∼220 μg/mL resulted in an increased amount of curcuminoids in the supernatant after centrifugation (Figure 3). However, an increase in the amount of curcuminoids in the dispersion beyond 220 μg/mL did not result in a further increase of curcuminoids in the supernatant, which indicates a saturation of the sites in the soluble components (i.e., soluble protein and β-

Table 1. Composition of Fractions Obtained upon Ultracentrifugation (20 400 g, 20 min, 22 °C) of Curcuminoid (25.8 μg/mL)−Oat Fiber 1% (w/w) Dispersion in 2% EtOH[a]

component	supernatant	precipitate	total (supernatant + precipitate)
wt fraction (g)	95.25 ± 0.13	4.74 ± 0.15	99.99
total solid (g/100 g dispersion)	0.28 ± 0.03	0.73 ± 0.03	1.01
protein (g/100g)	0.11 ± 0.02	0.18 ± 0.01	0.29
β-glucan (g/100g)	0.17 ± 0.01	0.11 ± 0.02	0.28
curcuminoids (%)	38.63 ± 2.7	41.10 ± 2.15	79.7[b]

[a]Data are the mean of three determinations ± standard deviation. [b]An additional 13.4 ± 0.7% of curcuminoids added was recovered from the washings from the beaker and the probe used for homogenization.

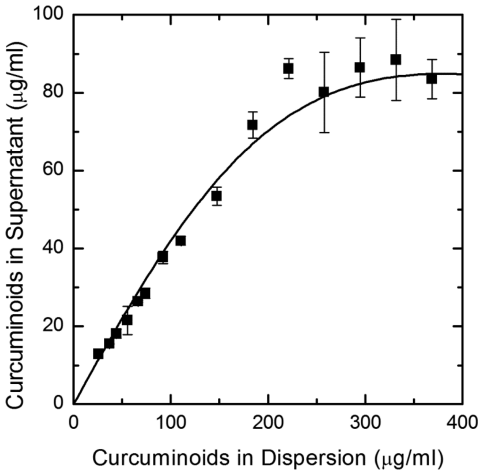

Figure 3. Concentration of curcuminoids in supernatant of 1% (w/w) oat fiber dispersion in 2% (v/v) EtOH as a function of total added curcuminoids in initial dispersion.

glucan components) of oat fiber. The highest amount of curcuminoids extracted from the supernatant corresponded to a concentration of ∼88 μg/mL (Figure 3). The solubility of curcuminoids in the soluble supernatant component of the oat fiber dispersion (in 2% v/v EtOH) increased by a factor of 21 over that in 2% v/v EtOH (4.1 μg/mL; this work) without oat fiber. This concentration of curcuminoids in the supernatant is also much higher than that of the reported solubility of curcumin in aqueous media (11 ng/mL, pH 5).[29] This result clearly demonstrated the ability of the soluble oat fiber components to carry curcuminoids in an aqueous system. The combined effects of hydrophobic interactions and hydrogen bonding that govern these reported interactions are likely responsible for the interactions with oat fiber and increased solubility observed.

The increase in curcuminoid solubility in the presence of biopolymers and synthetic polymers has been reported. For example, the addition of curcumin to soy protein (5% (w/v) in water) increased the curcumin solubility by 812-fold because of the formation of a complex, driven by hydrophobic interactions.[13] Micelles of hydrophobically modified starch have also been used to encapsulate curcumin, which resulted in a 1670-fold increase in curcumin solubility.[14] It was suggested that this increase in curcumin solubility was due to the combined effects of the transfer of curcumin into a more hydrophobic environment and hydrogen bonding between curcumin and the starch. Synthesized chemical polymers, including hydroxypropylated derivatives of β (HP-β-CD) and γ (HP-γ-CD) cyclodextrin (CD), also increased the solubility of curcumin to about 1700- and 4700-fold, respectively.[30] The

Table 2. Comparison of Major Reflections Observed in the XRD Spectra of Curcumin Crystals and Encapsulated Curcumin Preparations from Various Studies[a]

this study		Pan et al.[32]		Zi et al.[33]		Patel et al.[34]		Mohan et al.[35]	
2θ (deg)	intensity	2θ (deg)	intensity	2θ (deg)	intensity	2θ (deg)	intensity	2θ (deg)	intensity
7.9	94	∼7	∼490	-	-	-	-	-	-
8.9	191	∼8−9	∼1500	8.84	∼12500	8.90	∼500	-	-
12.2	127	∼12−13	∼1350	12.10	∼2500	12.26	∼350	12	-
14.5	139	∼15	∼2000	14.39	∼3000	14.54	∼490	14.3	-
15.1	93	-	-	-	-	-	-	-	-
15.8	92	-	-	-	-	-	-	-	-
16.3	80	∼16	∼1300	-	-	-	-	-	-
17.3	197	∼17−18	∼4200	17.20	∼13000	17.24	∼1100	17.1	-
18.2	148	∼18	∼3000	-	-	-	-	18.2	-
19.5	107	∼19	∼1600	-	-	-	-	18.6	-
21.2	108	∼21	∼2250	-	-	-	-	21	-
23.4	138	∼23	∼3600	23.30	∼2800	23.33	∼600	23	-
24.6	153	∼25	∼3400	24.50	∼2200	24.60	∼800	24.4	-
25.6	152	∼26	∼4100	25.52	∼2000	25.52	∼790	25.5	-
26.1	120	-	-	-	-	-	-	-	-
26.8	107	-	-	-	-	-	-	-	-
27.4	131	∼27	∼3300	-	-	-	-	27.2	-
29.0	110	∼28	∼2800	28.87	∼1500	-	-	-	-

[a]Note: "−" in the table refers to peaks that were not detected or reported.

solubilization of curcumin with various materials appears to be related to the binding of curcumin to hydrophobic regions of molecules. Compared to hydrophobically modified starch and soy protein, oat fiber is less hydrophobic in nature. CDs have a hydrophobic cavity and form inclusion complexes with curcumin.[29] The reduced availability and affinity of hydrophobic sites in oat fiber for curcumin compared to hydrophobically modified starch, soy protein, and CDs possibly explains the lower ability of curcumin to bind to oat fiber and hence its reduced ability to solubilize curcumin.

Crystallinity of Curcuminoids by X-ray Diffraction. Wide-angle XRD studies on the precipitated fraction obtained upon centrifugation of the curcuminoid (25.8 μg/mL)−oat fiber (1% w/w TS) dispersion in aqueous EtOH (2% v/v) were carried out to investigate if crystalline curcuminoid was entrapped in the precipitated fraction.

A powder dispersion of curcuminoid has characteristic peaks between 7 and 30 degrees, which suggest that the powder contains crystalline components (Table 2). The major reflection at ∼17 degrees and relative intensities of reflections are largely consistent with previous reports of curcuminoids in a crystalline form (Table 2). The differences observed are possibly due to the different preparations of curcuminoids used in the various studies.

The XRD spectrum of the precipitate obtained upon centrifugation of the curcuminoids−oat fiber dispersion has an absence of sharp peaks (Figure 4), which suggests that

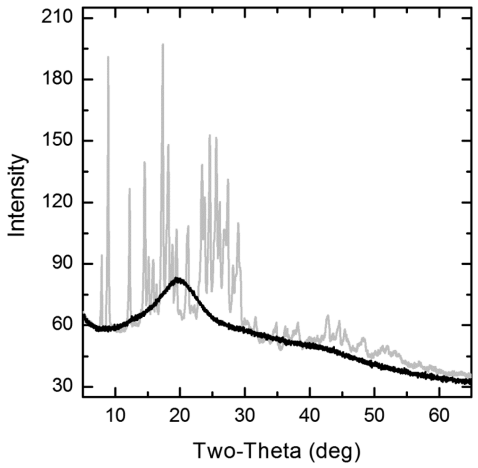

Figure 4. XRD spectra of curcuminoids present in the precipitate obtained upon centrifugation of a curcuminoid (25.8 μg/mL)−oat fiber (1% TS, w/w) dispersion (black) and spectra of the original curcuminoid powder (gray).

curcuminoids in the precipitate were less crystalline in character than the original curcuminoids powder. The broad reflection observed in the precipitated fraction of the curcuminoids−oat fiber dispersions at ∼19 degrees is a typical pattern of a more amorphous substance. The results suggest that the curcumin is in the form of an amorphous solid dispersion. Others have shown that amorphous solid dispersions are formed in a range of cellulose derivative matrices.[31] The curcuminoids in an amorphous form are desirable from a delivery viewpoint as it improves bioavailability.[31]

The position of the reflection (2θ value) observed for curcuminoids in the presence of oat fiber was at 19.4 deg. The corresponding values for curcumin/curcuminoids encapsulated with various materials were 11−12 and 10−20 deg with sodium caseinate,[32] 19 and 23 deg with soy protein,[33] 8 and 19 deg with zein,[34] and 16 and 22 deg with CD,[35] which show similar trends for the XRD spectrum of encapsulated curcuminoid in different encapsulant materials.

Storage Stability. Figure 5 shows the stability of curcuminoids in the presence of the whole curcuminoids−oat

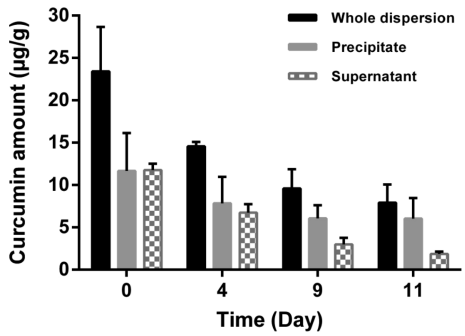

Figure 5. Amount of curcuminoids remaining during storage at 25 °C in the dispersion of curcuminoids−oat fiber (1% TS, w/w) and in the supernatant and precipitated fractions obtained upon centrifugation. Values are expressed as the content per g of the original dispersion.

fiber dispersion in 2% (v/v) EtOH and the supernatant and precipitated fractions of this dispersion during 11 days of storage at 25 °C. The concentration of curcuminoids decreased from 23.42 to 8.27 μg/mL in the whole oat fiber dispersion after 11 days. The degradation of the curcuminoids in the supernatant was faster than that in the precipitate (Figure 5). It is suggested that the difference between the stability of curcuminoid in the precipitate and supernatant is due to the insoluble curcuminoids in the amorphous state in precipitate. Others have shown that curcumin is stabilized against degradation when it is in the amorphous state.[31]

In conclusion, this study showed that both protein and β-glucan components of oat fiber are able to interact with curcuminoids and increase solubility in an aqueous solution of 2% v/v EtOH. It is possible that curcuminoids also interact with proteins and dietary fibers in the precipitated fraction. These findings illustrate the potential for the curcuminoid carrying capacity of oat fiber to be capitalized upon in the fortification of food with curcuminoids.

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Notes

The authors declare no competing financial interest.

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