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Protection of moisture-sensitive drugs with aqueous polymer coatings: Importance of coating and curing conditions

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ABSTRACT

The aim of this study was to better understand the importance of coating and curing conditions of moisture-protective polymer coatings. Tablets containing freeze–dried garlic powder were coated with aqueous solutions/dispersions of hydroxypropyl methylcellulose (HPMC), poly(vinyl alcohol), ethyl cellulose and poly(methacrylate-methylmethacrylates). The water content of the tablets during coating and during storage at different temperatures and relative humidities (RH) was determined gravimetrically. In addition, changes in the allicin (active ingredient in garlic powder) content were monitored. During the coating process, the water uptake was below 2.7% and no drug degradation was detectable. Thermally induced drug degradation occurred only at temperatures above the coating temperatures. Different polymer coatings effectively decreased the rate, but not the extent of water uptake during open storage at room temperature and 75% RH. Tablets coated with poly(vinyl alcohol) and poly(methacrylate-methylmethacrylates) showed the lowest moisture uptake rates (0.49 and 0.57%/d, respectively). Curing at elevated temperature after coating did not improve the moisture-protective ability of the polymeric films, but reduced the water content of the tablets. Drug stability was significantly improved with tablets coated with poly(vinyl alcohol) and poly(methacrylate-methylmethacrylates).

1. Introduction

Herbal medicines have been established world wide for the treatment and prophylaxis of various diseases. In several cases, the use of herbal drugs (e.g., traditional Chinese medicine) can be even more efficient than conventional western therapies (Sheeman, 1992). Herbal extracts are generally administered in high doses to achieve the desired therapeutic effects. Due to their complex composition and physicochemical properties, various instabilities of the pharmacologically active ingredients can occur (Campen et al., 1980). Drug instability can be caused by moisture, temperature, light and microorganisms (Ahlneck and Zografi, 1990; Badawy et al., 2001; Carstensen, 1988; Towns, 1995). Degradation due to moisture often plays a crucial role because of the generally highly hygroscopic nature of the herbal materials (Luftensteiner and Viernstein, 1999). These instabilities and the required high doses are the major challenges in the development of appropriate formulations for herbal drugs.

In the present study, garlic powder was used as a moisture-sensitive herbal material. Garlic (*Allium sativum* L., Alliaceae) is used as a spice and in medicines for the treatment of infections or for the prevention of stroke and arteriosclerosis (Krest and Keusgen, 1999; Wagner and Sendl, 1990). Its effects on blood coagulation, lipid- and cholesterol-metabolism, blood pressure as well as its antithrombic and antineoplastic activity are often discussed (Isensee et al., 1993; Koch, 1993). The biological activity is generally attributed to sulfur-containing compounds which are present in garlic as precursors (Wagner and Sendl, 1990; Lachmann et al., 1994). Alliin (a non-proteinogenic aminoacid: S-allyl-L-cysteinsulfoxid) is of particular importance. It is transformed into unstable allicin [2-propenyl-2-propenethiosulfinate] by an enzymatic conversation (alliinase) when fresh garlic is crunched or garlic powder is moistened (Fig. 1). During this transformation, garlic exhibits its pharmacological activity and characteristic smell (Krest and Keusgen, 1999). Allicin is often used as marker in stability tests and quantitative analysis of garlic powder by HPLC (Stricher, 1991; Winkler et al., 1992; Müller, 1989).

Different types of garlic-containing products are commercially available, containing either only garlic extracts or combinations with other herbal materials. In the first case, three major classes of products can be distinguished: (i) preparations containing oily macerates of garlic, (ii) products obtained from garlic–water steam distillates and (iii) formulations containing dried extracts of garlic (Luftensteiner and Viernstein, 1999; Sticher, 1991). Liquid (often aqueous and ethanolic based), semisolid as well as solid formu-

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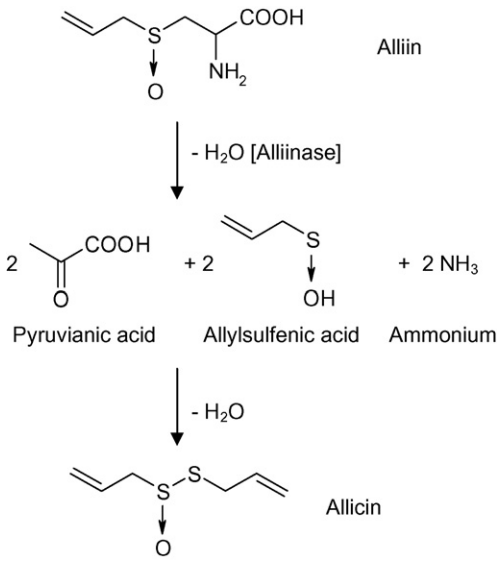

Fig. 1. Mechanism of alliin degradation in garlic powder.

lations (e.g., based on dried extracts) are used (Luftensteiner and Viernstein, 1999). Solid dosage forms (e.g., tablets, pellets and capsules) are often preferred because of the high patient compliance and improved chemical stability (Das Gupta et al., 1984).

Appropriate packaging material (Al-Zein et al., 1999; Allinson et al., 2001), protective polymer coatings (Cerea et al., 2004; Pearnchob et al., 2003) and the composition of the formulation (Du and Hoag, 2001) can minimize drug degradation in solid dosage forms. Nowadays, sugar coatings, which have been traditionally used for aesthetic and moisture-protective properties with herbal drugs, are more and more replaced by polymeric film coatings. The latter have the advantage of shorter processing times and reduced water influx during coating, resulting in increased drug stability. Commonly used polymeric film formers for moisture-protective coatings include hydroxymethylcellulose (HMC), hydroxypropyl methylcellose, poly(vinyl alcohol), ethylcellulose, shellac and poly(methacrylate-methylmethacrylates) (Gurny, 1976; Okhamafe and York, 1984; Okhamafe and York, 1985; Okhamafe and Iwebor, 1987; Petereit and Weisbrod, 1999; Pearnchob et al., 2003; Cerea et al., 2004). Water vapor permeation is dependent on the film composition (Banker et al., 1966; Baert and Remon, 1993), additives in the film (Okhamafe and Iwebor, 1987; Okhamafe and York, 1985; Parker et al., 1974) and the solvent system in which the polymer is dissolved or dispersed (List and Kassis, 1982). In particular, the effects of plasticizers in the coatings on the permeability of the polymeric films have been investigated (Johnson et al., 1991; Heinamaki et al., 1994; Guo, 1993). Generally, moisture permeates more rapidly through coatings containing hydrophilic plasticizers (List and Kassis, 1982), whereas the addition of hydrophobic plasticizers has no major effects on the water vapor permeability (Benita et al., 1986).

The coating process is a particularly critical step with respect to drug stability because the dosage forms are exposed to elevated temperature and/or humidity. The use of organic solvents for polymer coating causes environmental and toxicological concerns. On the other hand, aqueous polymer coatings can lead to water uptake into the core formulations and subsequent degradation of moisture-sensitive drugs (Ahlneck and Zografi, 1990; Badawy et al., 2001; Carstensen, 1988; Towns, 1995). Recently, solvent-free coating processes have been proposed, where the film forming agent is layered onto the surface of the cores directly as a powder (Cerea et al., 2004; Pearnchob et al., 2003). This type of coating process limits the use of water and decreases the processing times. However, due to incomplete film formation higher amounts of plasticizers and polymers are required and the exposure to elevated temperature is generally required to assure appropriate film formation.

The aim of this study was to better understand and improve the moisture-protective ability of aqueous polymer-based film coatings. Garlic powder was used as a moisture-sensitive herbal drug. It was freeze–dried to minimize the initial water content and compressed into tablets. Different types of polymers were studied as coating materials and the effects of several processing and formulation parameters on the resulting water uptake and drug stability were monitored and explained.

2. Materials and methods

2.1. Materials

The following materials were used as received: tablets containing 100 or 300 mg freeze–dried garlic powder (diameter: 8 and 12 mm, weight: 250 and 465 mg, respectively) (Lichtwer-Pharma, Berlin, Germany); partially hydrolyzed poly(vinyl alcohol) (Opadry® AMB white, Colorcon, Orpington, UK); poly(vinyl alcohol)–poly(ethylene glycol) copolymer (Kollicoat® IR, BASF, Ludwigshafen, Germany); hydroxypropyl methylcellulose (Methocel® E5, Colorcon, Orpington, UK; Sepifilm® LP010, Sepifilm® LP761 white, Sepifilm® LP770 white, Seppic, Paris, France); aqueous ethylcellulose dispersion (Aquacoat® ECD, FMC Biopolymer, Newark, USA); poly(methacrylate methylmethacrylate) copolymer (Eudragit® EPO, Degussa, Darmstadt, Germany); triethyl citrate (TEC, Morflex, Greensboro, USA).

2.2. Tablet coating

Tablets were coated in a perforated pan coater (15 rpm, air flow rate: 130 m^3/h, nozzle diameter: 1.2 mm, spraying pressure: 1.3 bar; Glatt® GC-300, Glatt, Binzen, Germany). Aqueous solutions or dispersions of the polymers (7–25%, w/w) were sprayed onto preheated tablets under the specific conditions recommended by the manufacturers (Table 1) to a coating level of 10% or 20% (w/w). Ten or 25% TEC (w/w, based on the polymer) was added as plasticizer to Methocel® E5 and Aquacoat® ECD, respectively. After coating, the tablets were cured for 3 or 24 h (as indicated) at 60 °C in a drying chamber (Heraeus T6120, Heraeus, Hanau, Germany).

Table 1
Coating conditions (perforated pan coater Glatt® GC-300, 15 rpm, air flow rate: 130 m^3/h, nozzle diameter: 1.2 mm, spraying pressure: 1.3 bar).

Type of coating formulation	Polymer concentration (%, w/w)	Inlet air temperature (°C)	Outlet air temperature (°C)	Spraying rate (g/min)
Methocel® E5	7	60	40	4.2
Sepifilm® LP010	7	60	41	4.5
Sepifilm® LP761	7	60	41	4.4
Sepifilm® LP770	7	60	41	4.5
Opadry® AMB	15	65	43	7.5
Kollicoat® IR	20	65	43	7.8
Aquacoat® ECD	25	60	40	4.2
Eudragit® EPO	9	45	30	7.3

2.3. Thermogravimetric analysis (TGA)

TGA was carried out using a thermobalance (Mettler® TG 50, Mettler, Giessen, Germany), coupled to a TA-controller (Mettler® TC 15, Mettler). The generated data was evaluated using the software STARe (version 6.01, Mettler). Samples (5–10 mg of pulverized tablets) were heated in open ceramic pans from 25 to 300 °C at a heating rate of 3 °C/min. The sample chamber was purged with dry nitrogen to avoid moisture uptake from the air. The change in mass was recorded.

2.4. Determination of the allicin content

The allicin content was determined by HPLC analysis after an enzymatic conversion of alliin into allicin. A defined amount of powdered sample (containing 100 mg garlic powder) was shaken with 2.5 ml water for 20 min at room temperature for a quantitative conversion of alliin. One hundred and five μl NaOH (40%, w/w) was added and the samples were further shaken for 2.5 min. The suspension was neutralized with 500 μl HCl (10%, w/w) and the pH adjusted to pH 5–7 by adding 500 μl phosphate buffer (pH 7.0). Then, methanol was added until a sample volume of 10 ml obtained. After centrifugation the supernatant was collected and analyzed with a LaChrom-HPLC system (Merck-Hitachi, Darmstadt, Germany) using a Spherisorb® ODS 2 (3 μm, 120 mm × 4 mm) column with MeOH/H_2O 70/30 as mobile phase (120–130 bar pressure, UV-detection at λ = 230 nm). Garlic powder with a standardized allicin content was used for a four point HPLC calibration ($n = 2$).

2.5. Determination of the water content

The water content was determined as mass loss upon drying using two different thermogravimetric methods: (a) at 100–105 °C in a halogen moisture analyzer for 20 min (Mettler® HR 75, Mettler), (b) at 105 °C in a drying chamber for 3 h (Heraeus T6120) ($n = 2$).

2.6. Determination of drug stability under "simulated" coating conditions

In order to "simulate" coating conditions (except for humidity), uncoated tablets were placed in the pan coater (Glatt® GC-300) and rotated for 4 h at 15 rpm in an unconditioned air stream of (130 m^3/h) at different temperatures (30, 40, 50, 60 and 70 °C) without spraying any coating solutions. Four hours was chosen as an average time needed for a standard aqueous coating process. The allicin and water contents were determined before and after the treatment (Sections 2.4 and 2.5a).

2.7. Determination of drug stability under storage conditions

Coated and uncoated tablets were openly stored at room temperature/75% RH [in a closed desiccator containing a saturated NaCl solution] for 5 and 10 d. The allicin content was determined before and after the treatment (Section 2.4).

2.8. Water uptake studies

The water content (in %, w/w) of freshly prepared tablets was determined as loss on drying [Section 2.5b; water content (%)(t_0)]. Tablets were openly stored at room temperature and 75% RH (in a closed desiccator containing a saturated NaCl solution). At predetermined time intervals, samples were withdrawn and accurately weighted [$m(t)$]. The water content (in %, w/w) as a function of time t was calculated as follows:

$$\text{water content}(\%)(t) = \frac{m_{\text{water}}(t)}{m(t)} 100\ \% \quad (1)$$

$$m_{\text{water}}(t) = \text{water content}(\%)(t_0)\text{m}(t_0) + m(t) - m(t_0) \quad (2)$$

where $m_{\text{water}}(t)$ denotes the amount of water in the sample at time t; $m(t_0)$ and $m(t)$ represent the total mass of the tablets at time $t = 0$ and t, respectively ($n = 3$).

3. Results and discussion

3.1. Thermal properties of uncoated tablets

TGA is a well established method to determine the thermal decomposition of natural products (Snyder et al., 2005). TGA-thermograms of uncoated tablets were characterized by three phases (Fig. 2). The mass was almost constant during the first phase (25–60 °C). Potential mass loss in this phase could be attributed to the removal of water adsorbed to the surface. However, this type of moisture was not present in the tablets. More tightly bound water was removed during the second phase, resulting in a mass loss starting at approximately 60–70 °C and leveling off at about 150 °C (most water is removed at this temperature). Thus, the water present in the tablets containing freeze–dried garlic powder was tightly bound because of the latter's highly hygroscopic nature. The samples decomposed during the third phase ($T > 150$ °C). As expected, the mass loss of tablets containing 300 mg garlic powder was more pronounced in stage two compared to tablets containing 100 mg (indicating a higher absolute water content, due to the higher content of the hygroscopic compound).

3.2. Water uptake and drug stability during the coating process

Since tablets are exposed to elevated temperatures and humidities during coating, their water and allicin contents were followed during this critical step. First, the water uptake and drug degradation under "simulated" coating conditions (at elevated temperature, but without spraying) were measured. The tablets (initial water content: 1.34%) took up water from the unconditioned air at

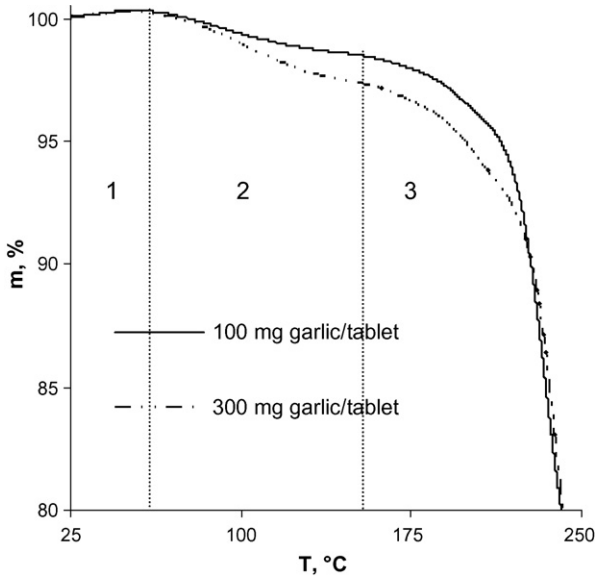

Fig. 2. TGA thermograms of tablets containing 100 or 300 mg freeze–dried garlic powder at a heating rate of 3 °C/min from 25 to 300 °C ("m, %" is the mass of the sample in % (w/w); 100% reference value = mass at $t = 0$).

Table 2
Water and allicin contents of uncoated tablets containing 100 mg freeze–dried garlic powder after 4 h exposure to elevated temperature in the rotating pan (without spraying any coating formulation, "simulated" coating conditions) (initial water content: 1.34%) (SD = standard deviation, $n = 2$).

Treatment (°C)	Water content (%)	SD	Allicin content (%)	SD
30	3.43	0.02	0.23	0.00
40	2.19	0.01	0.23	0.00
50	1.84	0.01	0.23	0.00
60	1.26	0.01	0.24	0.00
70	1.05	0.01	0.24	0.00

moderate coating temperatures (30–50 °C), whereas they lost water at temperatures above 60 °C (Table 2). This can be explained by the hygroscopic nature of the tablets (dominating at moderate temperatures) and increased water evaporation at higher temperatures (dominating above 60 °C). The threshold value of 60 °C correlates well with the thermograimetric analysis of the uncoated tablets (Fig. 2): only unbound water is removed below 60 °C, whereas bound water evaporates at higher temperatures.

The allicin content (initial content: 0.23%) did not significantly change during the "simulated" coating process, irrespective of the temperature (Table 2). These measurements were conducted using ambient, unconditioned air in the absence of aqueous coating formulations. During "real" aqueous coating the relative humidity in the pan is elevated and the effects of elevated temperature might be different. However, the drug stability was not affected even upon spraying an aqueous solution/dispersion under real coating conditions: The allicin content of tablets containing 300 mg freeze–dried garlic remained constant at 2.0–2.1 mg/tablet upon coating with Opadry® AMB or Eudragit® EPO [up to 10% (w/w) coating level] (Table 3, $t = 0$ d).

The water content of tablets containing 100 and 300 mg freeze–dried garlic powder was followed during pre-heating (phase 1), coating with Opadry® AMB [up to 20% (w/w) coating level] (phase 2) and subsequent drying in a drying chamber at 60 °C (phase 3) (Fig. 3). The pre-heating step of approx. 10 min (during which the tablets approach the coating temperature of 45 °C) aims to reduce the water uptake during the subsequent coating step. The water content increased only slightly, as was already observed during the "simulated" coating process (Table 2). In contrast, the water content increased dramatically as soon as the spraying of the coating solution started (phase 2). The water uptake rates decreased with further spraying (increasing coating level). This indicates a moisture protective effect of the initial polymeric film coating towards further spraying of the aqueous coating systems. Subsequent drying at 60 °C for up to 24 h led to a slight decrease in the water content indicating entrapment of water in the tablet core during the coatings process (phase 3). The initial sharp drop in water content during the drying phase could possibly be due to water being removed from the coating film while the subsequent gradual loss could come from water in the tablet core.

Table 3
Allicin content of uncoated and coated tablets [10% (w/w) coating level] containing 300 mg freeze–dried garlic powder before and after exposure to 75% RH and room temperature for 5 and 10 d ($n = 2$).

	Allicin content ± SD (mg/tablet)		
Time (d)	Uncoated	Opadry® AMB	Eudragit® E PO
0	2.01 ± 0.02	2.02 ± 0.01	2.06 ± 0.01
5	1.88 ± 0.00	1.99 ± 0.02	2.03 ± 0.00
10	1.87 ± 0.01	1.94 ± 0.02	1.99 ± 0.01

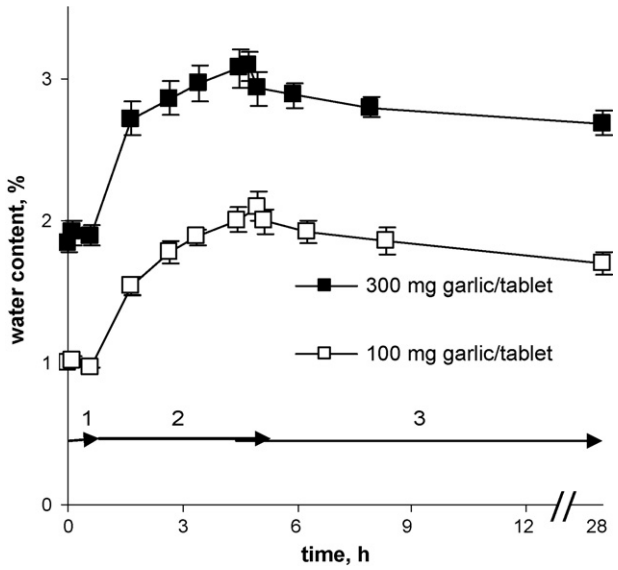

Fig. 3. Water content of tablets containing 100 or 300 mg freeze–dried garlic powder before, during and after coating with Opadry® AMB [20% (w/w) coating level]: (1) pre-heating, (2) coating, (3) curing.

3.3. Water uptake and drug stability during open storage at 75% RH

The stability of the herbal drug during storage strongly depends on the water content of the tablets. The degradation rate of alliin (catalyzed by enzymes) significantly increases with increasing amounts of water. Thus, the water content of the tablets was used as an indicator for storage stability. Tablets containing 100 mg freeze–dried garlic powder and coated with different aqueous polymer solutions/dispersions were studied.

Different types and coating levels of HPMC-based coatings were evaluated for their moisture protection during storage of the coated tablets at room temperature and 75% RH (Fig. 4). Methocel® E5 is a low viscosity HPMC type 2910, whereas Sepifilm® LP is a ready-to-use formulation containing HPMC (film-forming agent), cellulose (binder), stearic acid (hydrophobic plasticizer) and, optionally, pigments. The Sepifilm® LP types differ in their composition: the LP010 type contains no pigment and low amounts of stearic acid, the LP 770 type low amounts of pigments and stearic acid, and the LP761 type high amounts of stearic acid and pigments. Irrespective of the type of HPMC formulation, the resulting water uptake rate decreased with increasing coating level, indicating the moisture protective ability of the polymeric films. The water uptake rates determined at early time points ranged between 1.68 and 2.48%/d (Table 4). The initial (before storage) water content of the tablets increased from 1.0% to 2.8% with increasing coating level (the tablets took up more water during the longer spraying with aqueous coating solutions/dispersion at the higher coating levels) (Fig. 4). The extent of water uptake during open storage decreased only slightly with increasing coating level. Curing decreased the initial water content of the tablets, but did not significantly increase the moisture-protective ability of the coatings (Fig. 4, Table 5). The water uptake extent was very similar at 10% coating level.

Even though an increase of the coating level from 0% to 5% (w/w) Opadry® AMB [a poly(vinyl alcohol)-based formulation] led to a higher water content in the tablets at the beginning of the storage trial, a further increase up to 20% (w/w) did not lead to additional water uptake (Fig. 5A). In contrast, it resulted in a clear decrease in the water uptake rate during storage (from 1.00 to 0.31%/d), indicating the good moisture protective ability of this formulation. Curing of tablets coated with 20% (w/w) Opadry® AMB at 60 °C for either

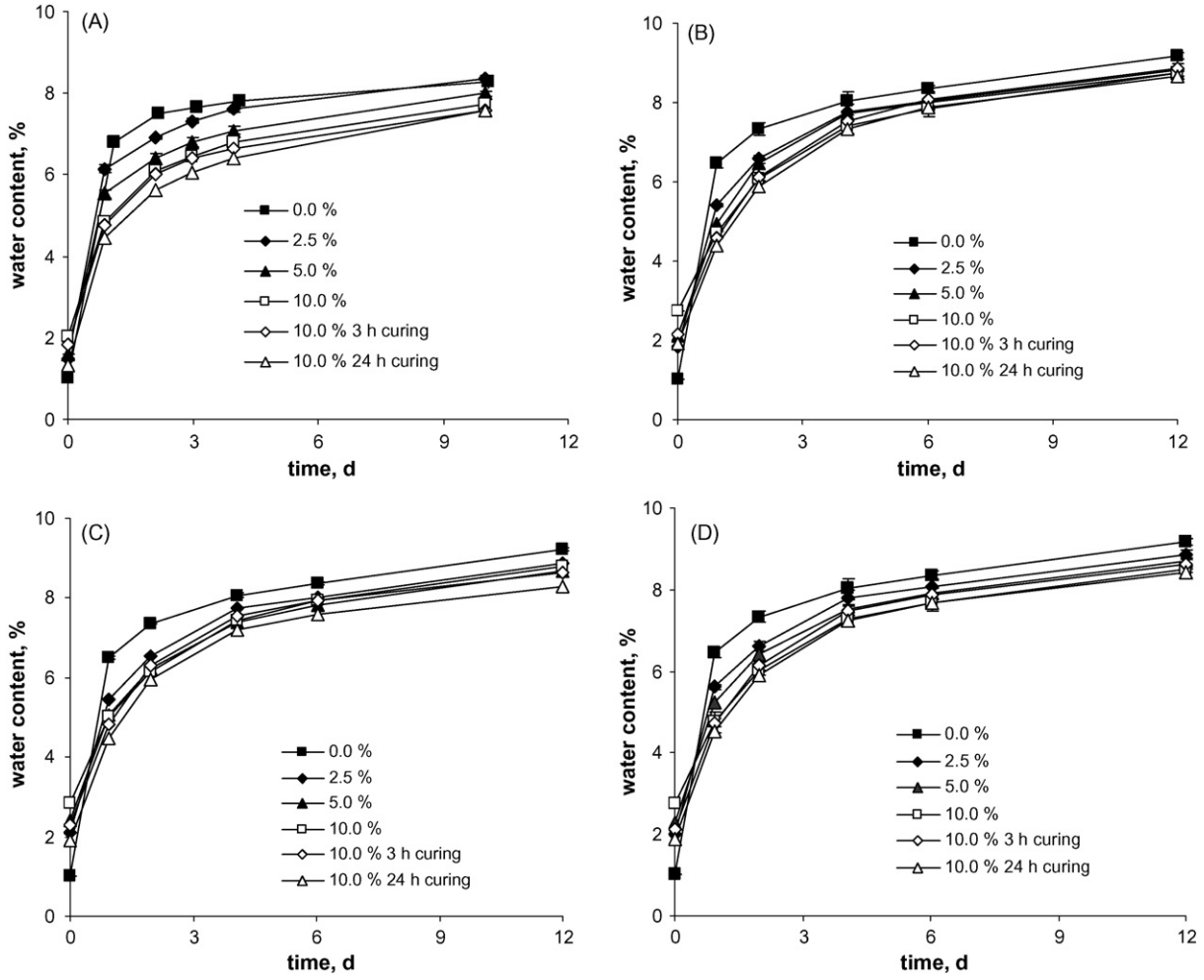

Fig. 4. Water uptake of tablets containing 100 mg freeze–dried garlic powder coated with different types of HPMC-based formulations upon exposure to 75% RH: (A) Methocel® E5, (B) Sepifilm® LP770, (C) Sepifilm® LP761, (D) Sepifilm® LP010 [coating level: 0-10% (w/w), as indicated].

3 or 24 h had no effect on the water uptake rate. Both, the observed water uptake rates (Fig. 5A) as well as the only slight decrease in water content during curing (Fig. 3) of Opadry® AMB-coated tablets indicates the low water vapor permeability and good moisture protective ability of this film coating.

In contrast to Opadry® AMB, Kollicoat® IR-coated tablets showed higher initial water uptake rates (up to 2.97%/d), which were similar for all coating levels. The extent in water uptake even increased with increasing coating level (Table 4, Fig. 5B). This can be attributed to the different chemical structures of the polymers: the poly(vinyl alcohol) (PVA) in Opadry® AMB is partially hydrolyzed, while the PVA in Kollicoat® IR is co-grafted with poly(ethylene glycol) (PEG, acting as an internal plasticizer). PEG is hygroscopic, thus explaining the higher rates and extent of water uptake of Kollicoat® IR-coated tablets when compared to Opadry® AMB-coated tablets.

Next, two water-insoluble polymers [ethylcellulose and Eudragit® EPO, a poly(methacrylate-methylmethacrylate)-copolymer] were investigated. With ethylcellulose-based formulations (Aquacoat® ECD), the water uptake rate decreased with increasing coating level (Fig. 6A). The rather low value of 1.22%/d at a coating level of 10% (w/w) (Table 4) can at least partially be attributed to the relatively high water uptake of the tablets during the coating process [initial water content of uncured tablets at the beginning of the storage trial: 3.67% (w/w)]. During curing at 60 °C for 24 h, relatively high amounts of water evaporated, resulting in lower initial water contents and, thus,

Table 4
Water uptake rates (in %/d) [determined from the linear portions of the water content (%) versus time profiles at early time points] of tablets containing 100 mg freeze–dried garlic powder coated with different types and amounts of polymers upon storage at 75% RH and room temperature.

Type of coating formulation	Coating level (%, w/w)					
	2.5	5.0	7.5	10.0	15.0	20.0
Methocel® E5	2.48	2.20	–	1.90	–	–
Sepifilm® LP010	2.40	2.22	–	1.69	–	–
Sepifilm® LP761	2.24	1.93	–	1.68	–	–
Sepifilm® LP770	2.33	2.10	–	1.68	–	–
Opadry® AMB	–	1.00	–	0.49	0.39	0.31
Kollicoat® IR	–	2.79	–	2.79	2.83	2.97
Aquacoat® ECD	–	1.91	–	1.22	–	–
Eudragit® EPO	1.72	1.15	0.70	0.57	–	–

Table 5
Effects of tablet curing at 60 °C after coating on the water uptake rates (in %/d) [determined from the linear portions of the water content (%) versus time profiles at early time points] of tablets containing 100 mg freeze–dried garlic powder coated with different types and amounts of polymers (indicated in the first column) upon open storage at 75% RH and room temperature.

Film coating	Curing	
	3 h	24 h
10% Methocel® E5	1.93	2.00
10% Sepifilm® LP010	2.01	2.02
10% Sepifilm® LP761	2.04	2.05
10% Sepifilm® LP770	2.03	2.03
20% Opadry® AMB	0.34	0.36
20% Kollicoat® IR	3.13	3.28
10% Aquacoat® ECD	1.28	2.14
10% Eudragit® EPO	0.51	0.50

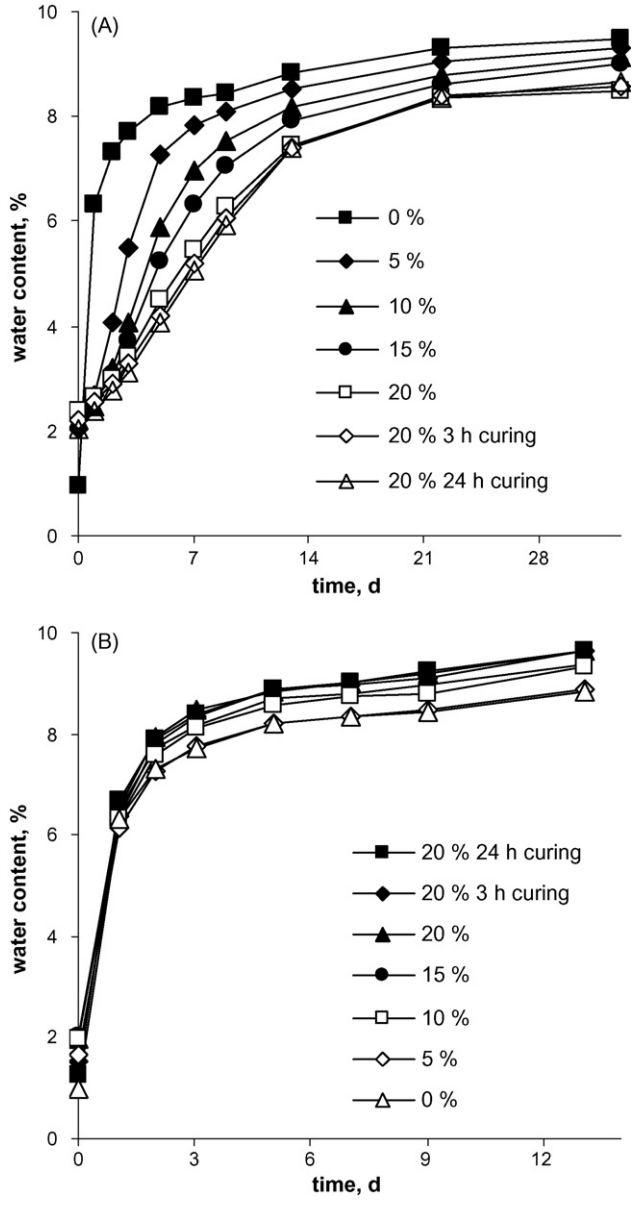

Fig. 5. Water uptake of tablets containing 100 mg freeze–dried garlic powder coated with different types of poly(vinyl alcohol)-based formulations upon exposure to 75% RH: (A) Opadry® AMB, (B) Kollicoat® IR [coating level: 0–20% (w/w), as indicated].

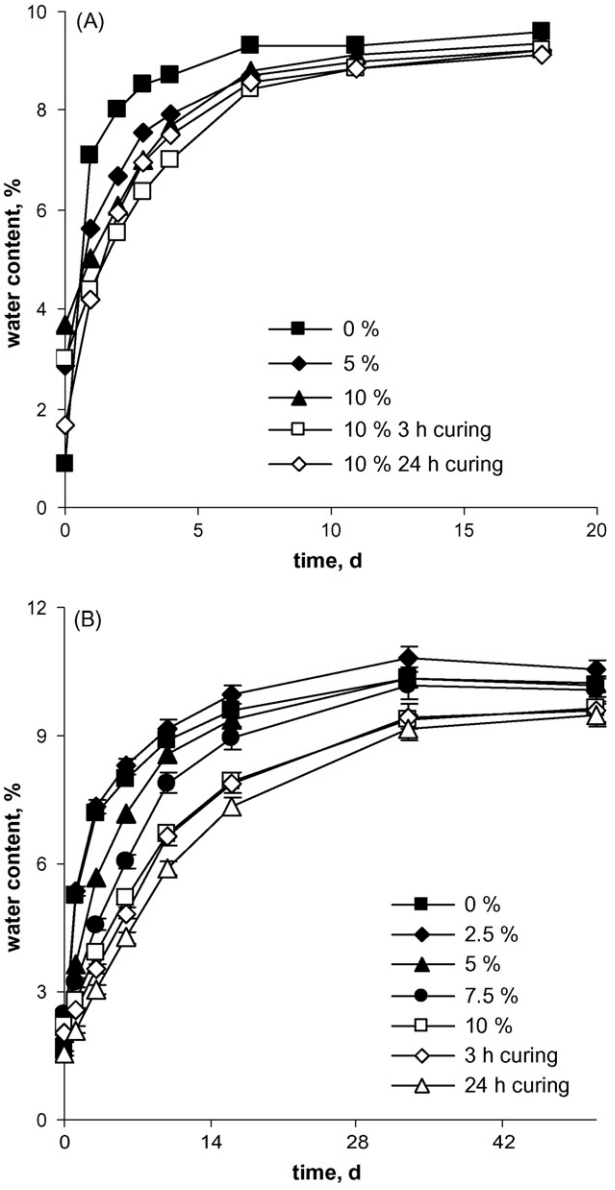

Fig. 6. Water uptake of tablets containing 100 mg freeze–dried garlic powder coated with: (A) Aquacoat® ECD, (B) Eudragit® EPO upon exposure to 75% RH [coating level: 0–10% (w/w), as indicated].

in increased water concentration gradients and increased water uptake rates (2.14%/d) (Table 5). This indicates a relatively high water vapor permeability of the ethylcellulose coatings, which could probably be attributed to non-complete film formation under the investigated coating and curing conditions. Continuous ethylcellulose films can be expected to show much lower water permeability (Saettone et al., 1995).

Tablets coated with Eudragit® EPO [a poly(methacrylate-methylmethacrylate)-copolymer] showed a similar reduction in the water uptake rate as Opadry® AMB-coated tablets (Fig. 6B and Tables 4 and 5). Interestingly and in contrast to all other coating formulations, curing at 60 °C for 3 and 24 h resulted in a decrease of the water uptake rate (from 0.57 to 0.50%/d, respectively). This can probably be attributed to further film formation, rendering the coatings less permeable. In addition, the time required to approach equilibrium was longer for Eudragit® EPO coatings compared to the other investigated formulations, indicating a good moisture-protective ability of this polymer.

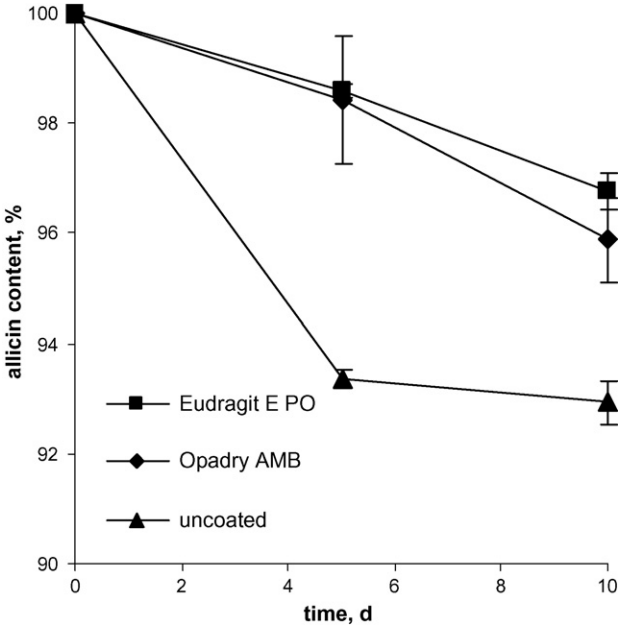

Fig. 7. Allicin content (%) of uncoated and coated tablets [10% (w/w) coating level] containing 300 mg freeze–dried garlic powder upon exposure to 75% RH at room temperature (the type of polymer coating is indicated in the figure).

The degradation kinetics of the drug was in good agreement with the water uptake behavior of the tablets during storage at room temperature and 75% RH (Table 3, Figs. 5A, 6B and 7). Thus, the water content was a good measure for drug stability in the investigated systems. Results obtained with Opadry® AMB and Eudragit® EPO (10%, w/w coating level) are shown in Fig. 7. High water uptake rates (uncoated tablets) led to accelerated drug degradation, while the polymer coatings clearly improved drug stability.

4. Conclusion

The stability of tablets containing freeze-dried garlic powder as a moisture-sensitive model compound was studied and could be improved. Water uptake during storage and, thus, drug degradation could significantly be reduced by applying moisture-protective aqueous polymer coatings. Interestingly, common coating conditions (RH, *T*) were found to be non-critical and did not affect drug stability. Eudragit® EPO and Opadry® AMB coatings could significantly reduce the moisture uptake rates of the tablets during storage, but not the extent (which only slightly decreased).

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