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Influence of Anti-Caking Agent on the Water Sorption Isotherm and Flow-ability Properties of Vacuum Dried Honey Powder

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Highlights (For Review)

- Effect of anti-caking agent addition to amorphous honey powder on its static and dynamic water sorption
- Effect of anti-caking agent addition to amorphous honey powder on its powder flow ability properties
- Effect of anti-caking agent addition on inhibiting recrystallization of amorphous sugar in vacuum-dried honey powder

1 **Influence of Anti-Caking Agent on the Water Sorption Isotherm and Flow-ability Properties of**
2 **Vacuum Dried Honey Powder**

3
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7
8 **ABSTRACT**

9 *Honey powder is a hygroscopic powder due to its composition and structure. The addition of anti-*
10 *caking agent was aimed to increase the stability of honey powder. The present study aimed to*
11 *study the influence of anti-caking agent on the water sorption isotherm and flow-ability*
12 *properties of vacuum dried honey powder. Anti-caking agents, calcium silicate and calcium*
13 *stearate, were added in honey powder. The addition of anti-caking agent influenced water*
14 *sorption and flow-ability properties of honey powder. Calcium silicate addition seemed not to*
15 *affect water sorption isotherm properties of honey powder, however, calcium stearate showed*
16 *more inhibiting effect of recrystallization and collapse of structure of amorphous honey powder.*
17 *Addition of anti-caking agent to honey powder increase flow-ability of honey powder and calcium*
18 *stearate seemed to increase flow-ability better than calcium silicate.*

19
20 **Key Words:** *Honey powder, anti-caking, calcium silicate, calcium stearate, flow-ability,*
21 *water sorption isotherm*

23 1. Introduction

24 Honey powder is a hygroscopic powder due to its composition and structure. The two
25 main sugars found in honey solids, fructose, and glucose, have very low glass transition
26 temperatures making honey powder hygroscopic (Bhandari and Howes, 1999). Nurhadi and Roos
27 (2016a) reported the production of honey powder by using vacuum drying technique and drying
28 aid materials (filler), maltodextrin. Anhydrous honey powder glass transition temperature was
29 reported over 30 to 43 °C depending on drying aid material type and composition (Nurhadi and
30 Roos, 2016a). Critical water content of honey powder was also very low, less than 2 % (g
31 water/100 g sample) (Nurhadi and Roos, 2016a). Honey powder might be in purely amorphous
32 or partially amorphous structure depending on process used (Nurhadi and Roos, 2016b). When
33 water is sorbed by honey powder during storage, water acts as a plasticizer, reduce glass
34 transition temperature of honey powder to lower than ambient temperature, results in
35 significant changes of macroscopic properties of honey powder, i.e. collapse which includes
36 phenomena such as stickiness, caking and shrinkage (Roos, 1995; Bhandari and Howes, 1999).
37 The rate of changes was dependent on the difference of ambient temperature to glass transition
38 temperature ($T-T_g$), the higher the difference was the faster was the rate at which the
39 macroscopic properties changed (Roos, 1995; Foster, Bronlund, Paterson, 2006; Roos and
40 Drusch, 2015). The change would reduce quality of honey powder and the powder is becoming
41 difficult to handle and difficult to flow.

42 Method to keep honey powder stable during storage is by storing it at a temperature
43 below its glass transition temperature or below its critical water activity (a_w). Additionally, anti-
44 caking agent could be used to maintain stability of sugar-rich powder such as honey powder
45 (Wolti-Chanes et al., 2007). Anti-caking agent (or flow conditioner/free flowing agent) is the
46 ingredient added at low quantity to increase stability and maintain free flowing properties of host
47 material (Barbosa-Canovas et al., 2005). Anti-caking agent mechanism is different for amorphous
48 and crystalline materials (Msagati, 2013). The mechanism of anti-caking agent might be by
49 competing for water with host material, acting as a water barrier, eliminating surface friction and
50 inhibiting crystal growth (Barbosa-Canovas et al., 2005 and Lipasek et al., 2012). Anti-caking agent
51 is classified as natural (such as kaolin, talc, and bentonite/silicate material) or synthetic when

52 manufactured from raw materials such as silicon dioxide (Msagati, 2013). Lipasek et al (2012)
53 reported the use of silicon dioxide, calcium silicate and calcium stearate up to 2 % as anti-caking
54 agent in host powder of crystalline material. The addition of anti-caking agent might affect water
55 sorption isotherm and flowing properties of host powder. The addition of anti-caking agent into
56 crystalline material did not change the shape of water sorption isotherm and some anti-caking
57 agent showed delaying deliquescence of crystalline material (Lipasek, Taylor and Mauer, 2011
58 and Lipasek et al., 2012).

59 Powder flow-ability is more complex than fluid (Xanthakis et al., 2015). Powder flow-
60 ability is affected by material properties and stress history of material during processing (Koynov,
61 Glasser, Muzzio, 2015). Powder flow-ability is affected by internal factor such as particle size and
62 distribution and external factor such as air humidity and temperature (Barbosa-Canovas et al.,
63 2005). Powder flow-ability is one of powder bulk properties (Barbosa-Canovas et al., 2005).
64 Powder would flow if the load acting on the powder is bigger than the powder strength (or the
65 bulk structure of powder failed and start moving) (Barbosa-Canovas et al., 2005). Barbosa-
66 Canovas et al (2005) considered powder flow-ability as a failure phenomenon. Two main
67 properties used to describe the flow-ability of powder are failure function and effective angle of
68 internal friction. Failure function correlates major principal consolidation stress (MPS) and
69 unconfined failure strength (UFS) to deduce the value of flow index. The correlation between
70 MPS and UFS is linear and the inverse slope of the best fit linear line equals to the flow index
71 (Barbosa-Canovas et al., 2005, Koynov, Glasser and Muzzio, 2015). The slope describes the
72 change of stress needed to induce the powder flow. The lower is the slope, the more free flowing
73 properties of the powder exist. The effective angle of internal friction is a property that describes
74 the inter particle interaction (Barbosa-Canovas et al., 2005) and powder with a low value of
75 effective angle is considered as a free flowing powder. The current study was aimed to investigate
76 the influence of anti-caking agents on water sorption and flow-ability properties of anhydrous
77 vacuum-dried honey powder.

78

79 **2. Materials and Methods**

80 **2.1. Honey Powder**

81 Honey was bought from local supermarket (Boyne valley Honey Brand) in Ireland.
82 Deionized water was used from KB scientific (Cork, Ireland) and maltodextrin DE 10 (M100) was
83 obtained from Grain processing corporation (IA, USA). Honey-maltodextrin solutions (total solid
84 43 % and ratio honey: maltodextrin = 6:4 and 4:6 (honey composition of 60 % and 40 % per
85 total solid, respectively)) were prepared on petri dishes with perforated covers for drying in
86 vacuum oven (WTB Binder, Germany) at temperature 60 °C for 3 hours. The mixture of honey,
87 maltodextrin and water is named as HMW. HMW 4:6 and HMW 6:4 referred to honey powder with
88 honey composition of 40 % and 60 % per total solid respectively. The dried samples were ground and
89 stored in desiccator over P₂O₅ (Sigma-Aldrich) for further analysis

91 92 **2.2. Mixing Honey Powder and Anti-Caking Agent**

93 Anti-caking agents, calcium silicate and calcium stearate (Sigma-Aldrich), were used. Anti-
94 caking agents in Erlenmeyer flask and honey powder were added gradually based on geometric
95 mixing principle to obtain an even distribution. Each addition of honey powder was followed by
96 mixing with spatula.

97 98 **2.3. Water Sorption Isotherm**

99 **2.3.1. Static water sorption**

100 Static water sorption was prepared by storing sample of dried honey powder (± 1 gram) in
101 desiccator over various saturated salt solutions. Seven different salt solutions were put in
102 desiccator to adjust the relative humidity (RH). The salt solutions used were LiCl, CH₃COOK,
103 MgCl₂, K₂CO₃, Mg (NO₃)₂, NaNO₂, and NaCl (Sigma Chemical Co., St. Louise, MO. U.S.A) to adjust
104 RH value of 11 %, 23 %, 33 %, 43 %, 52 %, 65 % and 75 %, respectively (Roos, 1995). The weight
105 change of samples was monitored regularly (every day) for three weeks or until steady weight
106 was reached. The water content of samples from each desiccator were determined by drying in
107 vacuum oven at 100 °C for 6 hours. The data of water content of honey powder and their

108 corresponding water activity was used to make water sorption isotherm (WSI) curve. The
109 Guggenheim-Anderson-deBoer (GAB) equation was used as a model of WSI.

$$110 \quad X = \frac{X_m C K a_w}{(1 - K a_w)(1 + (C - 1)K a_w)} \quad (1)$$

111

112 Where,

113 X = water content (g water/ g dry solid)

114 a_w = water activity

115 X_m = monolayer water content

116 X_m , C , and K are constants

117

118 **2.3.2. Dynamic water sorption (Dynamic Dew point Isotherm/DDI)**

119 Dried sample (about 500 mg) was used in DDI (Decagon Devices, Inc. Pulman WA, USA)
120 measurements. The adsorption direction of dynamic water sorption was set up. The
121 measurement were conditioned as follows, temperature of 25 °C, air flow of 300 ml/min and a_w
122 range starting from 0.1 to 0.85. In DDI adsorption direction, the wet air pass over the dried
123 sample and the sample would adsorb moisture from the air. If the initial water activity of dried
124 sample higher than 0.1 a_w , the dry air would pass over the sample until its water activity less than
125 0.1, then adsorption direction would be started. The data of sample weight change and its
126 corresponding water activity were recorded at certain interval time. The initial water content of
127 dried sample was determined by reducing water activity below 0.1 a_w and the predicted water
128 content then processed by DDI software (SorpTract Software, Decagon, Device Inc., Pulman WA,
129 USA). The data collection continued until the final set water activity was reached. The data of
130 sample weight changes were converted into data of sample water content. Finally the data of
131 sample water content and its corresponding water activity would be used to draw dynamic water
132 sorption curve.

133

134 **2.4. Tapped Density**

135 Honey powder sample was put in 25 ml measuring cylinder until fully covered the volume stated.

136 The measuring cylinder with honey powder inside then was put in tapped density meter (J.

137 Engelsmann AG, Germany) and tapping was done for 100 times. The end volume was then
138 recorded. Hausner Ratio (H_R) was calculated as followed (Barbosa-Cannovas et al., 2005):

139

$$140 \quad H_R = \frac{\rho_\infty}{\rho_o}$$

141 Where :

142 ρ_∞ = tapped density (bulk density of powder after tapping)

143 ρ_o = initial loose bulk density

144

145 **2.5. Powder Flow ability**

146 Flow ability of honey powder was measured by using Powder Flow tester (Brookfield, USA).
147 Sample of honey powder was put in trough whose annular shape and flattened with inner catch
148 tray. The trough has volume 38 cc. the initial weight of trough and the weight after sample
149 addition were recorded. The vane lid was then moved down to cover the trough. The vane lid
150 had diameter of 12.7 cm and curved profile. Standard flow test was set to run the experiment.
151 The trough then rotated while powder consolidated/compressed. Five consolidation stresses
152 were used. Five consolidation stresses used were 0.795, 1.607, 3.246, 6.559 and 13.252 kPa. As
153 an example at consolidation stress of 0.795 kPa, the 3 stresses set points used were 0.795 KPa
154 and the other two stresses lower than 0.795 kPa (0.265 and 0.536 kPa) (Fig. 1). The trough rotated
155 until steady flow reached and then the shear stress and normal stress were recorded. Data of
156 normal stress and shear stress were recorded for each consolidation stress. From Fig. 1, major
157 principal consolidation stress (MPS) and unconfined failure strength (UFS) were determined for
158 each consolidation stress with the use of powder flow pro. V1.2 Build 19 (Brookfield, USA). The
159 best fit line of normal stress and shear stress was called as yield locus and Mohr's semi-circle was
160 used to determine MPS and UFS (Barbosa-Cannovas et al., 2005 and Koynov, Glasser and Muzzio,
161 2015). UFS was determined with the use of Mohr's semi-circle which passing through origin point
162 and tangent to the yield locus while MPS was determined with the use of Mohr's semi-circle
163 which passing through pre shear consolidation stress (0.597 KPa) and tangent to the yield locus.
164 MPS and UFS represented the condition for the critical state and critical failure respectively

165 (Koynov, Glasser dan Muzzio, 2015). Effective yield locus was determined based on the line which
166 passing through origin and tangent to bigger Mohr's semi-circle and the angle between x-axes
167 and effective yield locus was called as effective angle of internal friction (Barbosa-Cannovas et
168 al., 2005). The data between MPS and UFS for every consolidation stress was then correlated to
169 determine flow factor index. Flow factor index was the inverse of slope of best fit linear line
170 between MPS and UFS.

171 Based on the value of flow factor index (ff), flow ability of a powder can be classified as (Barbosa-
172 Cannovas et al., 2005).

173 ff < 1 non flowing

174 1 < ff < 2 very cohesive

175 2 < ff < 4 cohesive

176 4 < ff < 10 easy flowing

177 ff > 10 free flowing

178

179

180 **Fig 1.** Yield Locus, effective yield locus, and Mohr's stress semi-circle from a sample of honey
181 powder (HMW 4:6) flow ability measurement by powder flow tester at 0.795 kPa consolidation
182 stress.

183

184 3. Results and Discussion

185 3.1. Water Sorption Isotherm

186 Water sorption isotherm of honey powder was done by using static/conventional and
187 dynamic method (DDI method). Even though the data from dynamic water sorption could not be
188 compared with data obtained from conventional method in calculating water sorption model
189 (such as GAB and BET model) (Schmidt and Lee, 2012), the DDI data could be used to study the
190 properties changes related to their corresponding water activities (Romani et al., 2016) such as
191 critical water activity determination (Yuan, Carter and Schmidt, 2011; Carter and Schmidt, 2012),
192 deliquescent point (Ghorab et al., 2014) and amorphous content (Nurhadi and Roos, 2016b).
193 From Fig. 2, it can be seen that addition of anti-caking agent (2%) to host powder of honey
194 powder did not change shape of WSI and the WSI were classified as type II of Brunauer water
195 sorption isotherm classification (Labuza and Altunakar, 2007). Nurhadi and Roos (2016a) also
196 reported that honey powder had type II of Brunauer water sorption isotherm classification. The
197 result agreed with those reported by Lipasek, Taylor and Mauer (2011) that the anti-caking agent
198 did not change the WSI shape of deliquescent material. As shown in Fig. 2, anti-caking agent
199 addition to honey powder also did not change its corresponding monolayer water content.

200

201

202 **Fig. 2.** Static water sorption isotherm of honey powder and honey powder with addition of anti-
203 caking agent and GAB parameter for each treatment.

204

205 Honey powder (maltodextrin ratio of 60 % per total solid) with calcium stearate addition
206 (2%) had higher water sorption than other two treatments of honey powder over water activity
207 (a_w) range of 0.44-0.76 (Fig. 2). As shown by Fig. 3a, the significant increase of water sorption of
208 honey powder occurred above a critical water activity (around 0.35 a_w). The Ca_w of honey powder
209 was higher than the Ca_w of honey powder (determined based on static water sorption) reported
210 by Nurhadi and Roos (2016a). The different result was caused by the different water sorption
211 method and the Ca_w obtained from dynamic WSI determination usually higher than the Ca_w value
212 based on static WSI and DSC (differential scanning calorimeter) glass transition measurement
213 (Carter and Schmidt, 2012). The critical value obtained by DDI method is much affected by the

214 flow rate of air over the sample during the measurement. The higher is the air flow rate, the
215 higher is the critical water activity obtained (Yuan, Carter and Schmidt, 2011). The Ca_w from
216 normal method (DSC and WSI method) might be equal to the Ca_w obtained from DDI method by
217 extrapolating the Ca_w at zero flow rate (Yuan, Carter and Schmidt, 2011). From Fig. 3.a. It could
218 be seen that anti-caking addition seemed not to change the critical water activity of honey
219 powder. The critical water activity was correlated with the significant increase of water sorption
220 due to transition from glassy structure to rubbery structure of amorphous component (Yuan,
221 Carter and Schmidt, 2011; Carter and Schmidt, 2012). After critical water activity surpassed, the
222 macroscopic properties such as crystallization of amorphous components and caking increased
223 significantly (Nurhadi and Roos, 2016b). As shown in Fig. 3a, there were differences in water
224 sorption after 0.5 a_w between honey powder with calcium stearate and other two honey powders
225 (honey powder and honey powder with calcium silicate). From DDI WSI result, the “equilibrium
226 water content” for both calcium stearate and calcium silicate corresponded to 0.1-0.8 a_w , were
227 of 0.2 % - 0.5% and 1.8 % - 6.0 %, respectively. The low water sorption of both calcium stearate
228 and calcium silicate were also reported by Lipasek et al. (2012).

229 The clearer differences of water sorption behavior between honey powders are shown in
230 Fig. 3b. Nurhadi and Roos (2016b) used first derivative of DDI WSI curve to show crystallization
231 of amorphous components during water sorption which appeared as a peak and the area of peak
232 correlated to the extent of crystallization occurred. It seemed that the crystallization of
233 amorphous components of honey powder occurred, however, the inhibition of crystallization
234 was apparent in honey powder with addition of calcium stearate. Honey powder without anti-
235 caking agent and honey powder with calcium silicate had more complete peak than the honey
236 powder with calcium stearate (Fig. 3b).

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b.

242 **Fig. 3.** Dynamic water sorption of honey powder and honey powder with the addition of anti-
243 caking agent (a), first derivative curve of dynamic water sorption of honey powder and honey
244 powder with the addition of anti-caking agent (b).
245

246 From static WSI experiment, the collapsed structure of honey powder appeared in honey
247 powder without anti-caking agent and honey powder with calcium silicate starting at 0.44 a_w
248 while collapse did not occur in honey powder with calcium stearate (Fig. 4). However at higher
249 a_w , honey powder with Calcium stearate addition also showed stickiness and lump phenomena
250 (0.65 and 0.75 a_w) and need tapping the vial several time to move out the powder from the vial.
251 Calcium stearate act as a barrier and due to its hydrophobic properties to repel water from
252 ambient air to the host particle (honey powder) that might show some inhibition effect of
253 crystallization of amorphous sugar (maintaining structural integrity) and collapse. Lipasek et al.
254 (2012) explained the ability of calcium stearate as moisture barrier between particles that might
255 interrupt bridging mechanism as an initial step of collapse occurred. Murrieta et al. (2011) stated
256 the collapsed structure of milk powder was triggered by recrystallization of amorphous lactose
257 in milk powder. The collapse phenomena occurred when Ca_w surpassed and caused physical and
258 chemical changes such as non-enzymatic browning reaction (Roos, 1995, Roos and Drusch, 2015).
259 Thus it could be shown that the addition of anti-caking agent (Calcium stearate) into honey
260 powder gave some effect of inhibition of crystallization and collapse of amorphous structure of
261 honey powder during water sorption experiment. That explained the phenomena occurring in
262 static WSI of honey powder (Fig. 2) where honey powder with calcium stearate had higher water
263 sorption than the other two honey powders due to recrystallization inhibition of amorphous
264 sugar in honey powder. The addition of anti-caking agent, calcium silicate and calcium stearate
265 at 1% in honey powder showed the same result as those with 2% (data not shown). The
266 disadvantages of calcium stearate addition are related to its taste and solubility.

267

268

269 **Fig. 4.** Honey powder and honey powder with addition of anti-caking agent after reaching
270 equilibrium at various water activity, from top to bottom correspond to honey powder, honey
271 powder + 2 % calcium stearate and honey powder + 2 % calcium silicate, respectively.
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3.2. Flow-ability

In order to work optimally as anti-caking agent, there should be interaction or surface affinity between anti-caking agent and host powder (Barbosa-Canovas et al., 2005). The interaction is indicated by the increase of bulk density of host powder after addition of an anti-caking agent (Barbosa-Canovas et al., 2005). As shown in Table 1, the addition of anti-caking agent (calcium stearate and calcium silicate) increased bulk density from 0.59 to 0.64-0.66 (g/cm³). The increase of bulk density showed the high surface affinity between anti-caking and host particle and if it is not, anti-caking agent could fill the void between host particles powder and no increase of bulk density may occur (Barbosa-Canovas et al., 2005).

Table 1. Parameters of honey powder obtained from powder flow tester and tapped density tester.

Flow-ability of honey powder with higher maltodextrin ratio was better than the lower ratio. As given in Table 1 and Fig. 5, the flow-ability index of honey powder increased from cohesive to easy flowing powder when the ratio of maltodextrin to honey increased from 40 % to 60 % (solid ratio). Honey powder with lower maltodextrin ratio had lower glass transition temperature (Nurhadi and Roos, 2016a) and tended to be more hygroscopic. The DDI critical water activity of honey powder increased (from around 0.3 a_w to 0.35 a_w) when the maltodextrin ratio to honey increased from 40 % to 60 % (per total solid) (Fig. 6). Stoklosa et al. (2012) stated that flow-ability of powder was influenced significantly by external conditions such as air relative humidity of storage. When water was adsorbed by honey powder, water acted as a plasticizer and reduced glass transition temperature of honey powder to below ambient temperature (Roos and Drusch, 2015) and honey powder became more sticky and difficult to flow.

302 **Fig. 5.** The flow-ability characteristic of honey powder and honey powder with addition of anti-
303 caking agent.

304

305

306 **Fig. 6.** Dynamic water sorption of honey powder at different ratio of maltodextrin DE 10

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308 Instead of increasing the ratio of maltodextrin as a drying aid material, anti-caking agent
309 might be used to improve the flow-ability of honey powder. As can be seen in Table 1 and Fig. 5,
310 the addition of anti-caking agent 2 % (both calcium stearate and calcium silicate) could increase
311 the flow-ability properties of honey powder from an easy flowing to a free flowing powder.
312 Density properties were also used as an indication of powder flow-ability (Barbosa-Canovas et
313 al., 2005 and Xanthakis, Ommen and Ahrne, 2015). Relative decrease of bulk density after
314 compaction or tapping of powder was an indicator that the powder had good flow-ability
315 properties (Barbosa-Canovas et al., 2005). From Table 1, based on the value of Hausner ratio (H_R),
316 the honey powders (excluding honey powder with lower maltodextrin ratio, HMW 6:4) were
317 classified as a medium flowing powder while HMW 6:4 was classified as a difficult flowing
318 powder. The increasing trend of bulk density value after compaction in powder flow-ability tester
319 of honey powder with anti-caking agent were smaller than that of honey powder with anti-caking
320 agent and the result complied with the flow index results. However, the contrary result based on
321 density measurement was found in honey powder with different maltodextrin ratio. The contrary
322 result of flow-ability measurement based on density properties was also reported by Xanthakis,
323 Ommen, and Ahrne (2015).

324 Flow-ability of powder was determined as a failure function in term of flow index as
325 explained in Barbosa-Canovas et al (2005). In addition to flow index, the effective angel of
326 internal friction can also be used to determine the flow-ability properties of honey powder. The
327 lower the value of effective angle of internal friction, the more free flowing properties the
328 powder has (Barbosa-Canovas et al., 2005). As shown in Fig. 7, honey powder with calcium
329 stearate had the lowest effective angle of internal friction followed by both honey powder
330 without anti-caking agent and honey powder with calcium silicate and honey powder with lower
331 maltodextrin ratio (HMW 6:4). The effective angle of internal friction is a property that described

332 inter-particle interaction of powder. The lower value of the angle indicated a smoother surface
333 interaction between particles in the powder. Compared to calcium silicate, calcium stearate has
334 bigger molecular size and had ability to elongate and narrow better than calcium silicate to give
335 protection of the surface more extensively. Lipasek et al (2012) also reported calcium stearate as
336 the best anti-caking agent in reducing effective angle of internal friction of crystalline sucrose.

337

338

339 **Fig. 7.** Effective angle of internal friction of honey powder and honey powder with addition of
340 anti-caking agent.

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342

343 4. Conclusion

344 Anti-caking agent calcium silicate and calcium stearate were added into honey powder.
345 The addition of anti-caking agent influenced water sorption and flow-ability properties of honey
346 powder. Calcium silicate addition seemed not to affect water sorption isotherm properties of
347 honey powder, however calcium stearate showed some inhibiting effect of recrystallization and
348 collapse of structure of amorphous components of honey powder. Addition of anti-caking agent
349 to honey powder increase flow-ability of honey powder and calcium stearate seemed to increase
350 flow-ability better than calcium silicate. Addition of anti-caking agent increased flow-ability of
351 honey powder from an easy flowing to a free flowing powder and calcium stearate showed
352 significant reduction of internal friction between particles of honey powder that contributed the
353 powder becoming more free flowing.

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ACCEPTED MANUSCRIPT

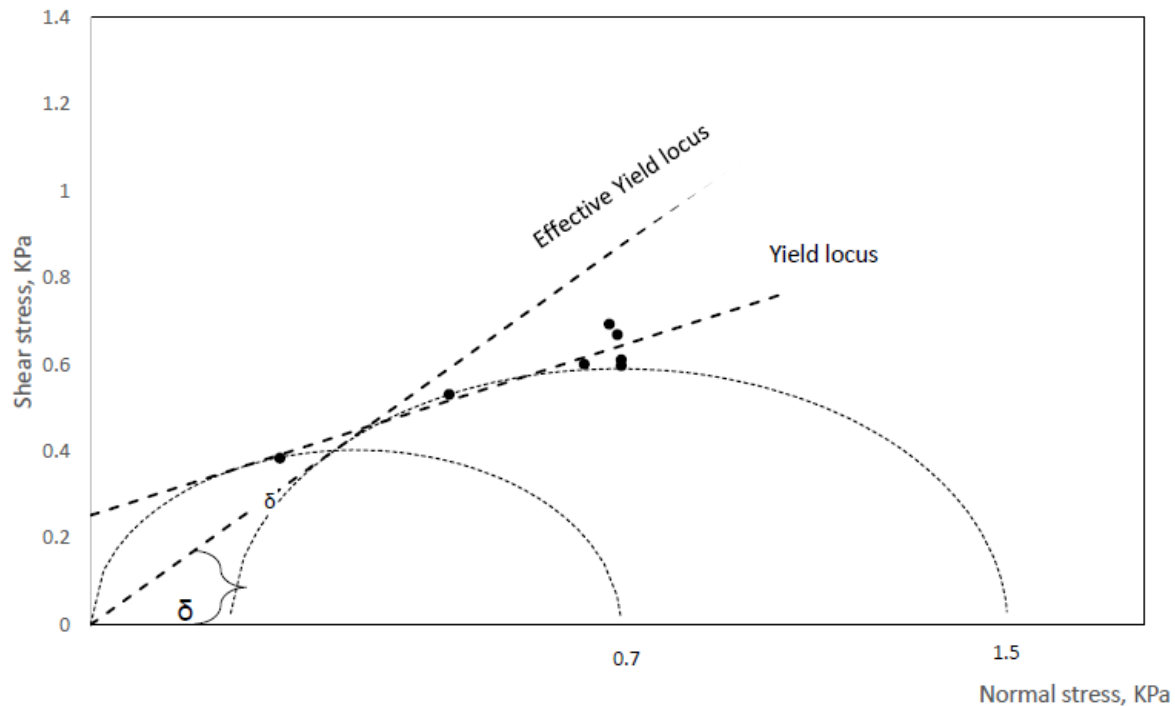


Fig 1. Yield Locus, effective yield locus, and Mohr's stress semi-circle from a sample of honey powder (HMW 4:6) flow ability measurement by powder flow tester at 0.795 kPa consolidation stress.

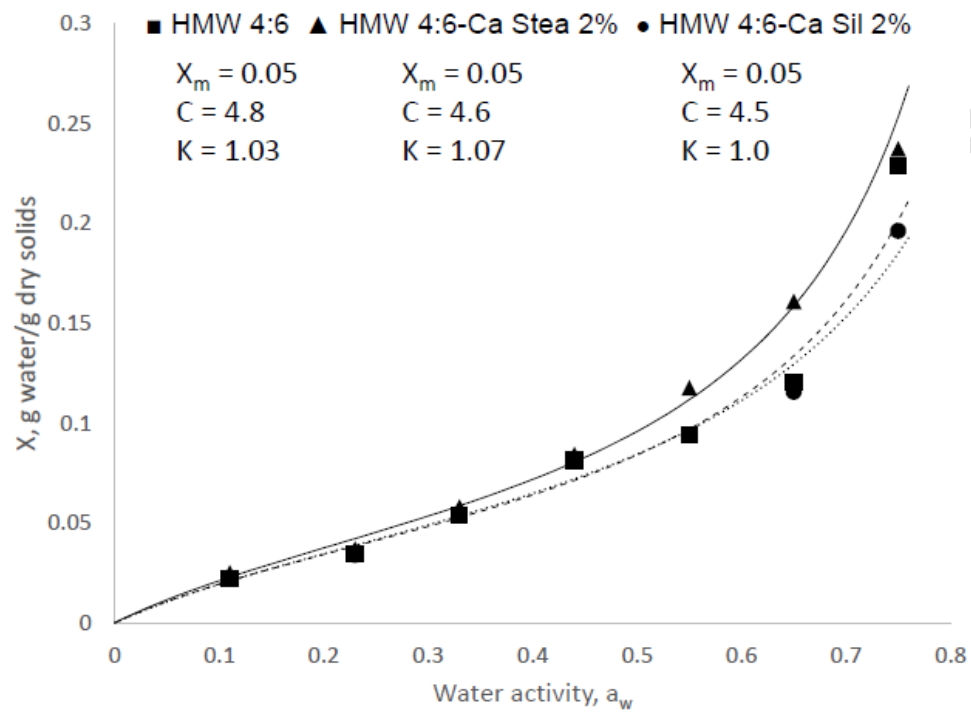
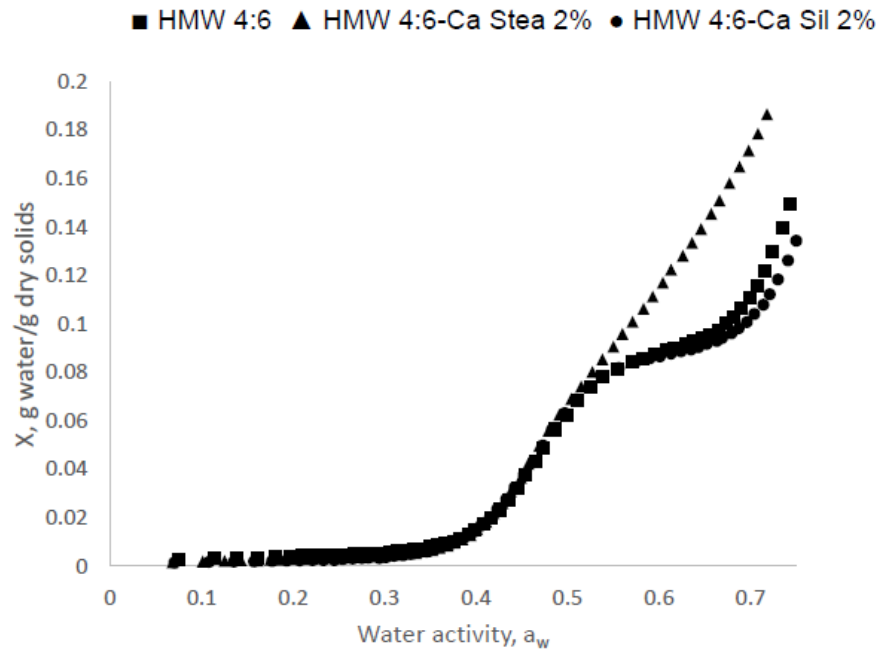
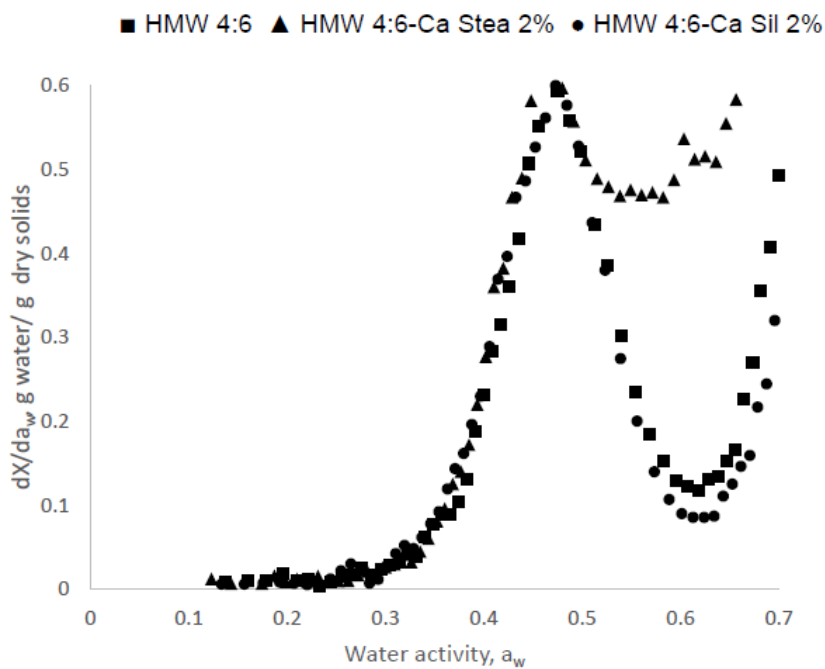


Fig. 2. Static water sorption isotherm of honey powder and honey powder with addition of anti-caking agent and GAB parameter for each treatment.



a.



b.

Fig. 3. Dynamic water sorption of honey powder and honey powder with the addition of anti-caking agent (a), first derivative curve of dynamic water sorption of honey powder and honey powder with the addition of anti-caking agent (b).

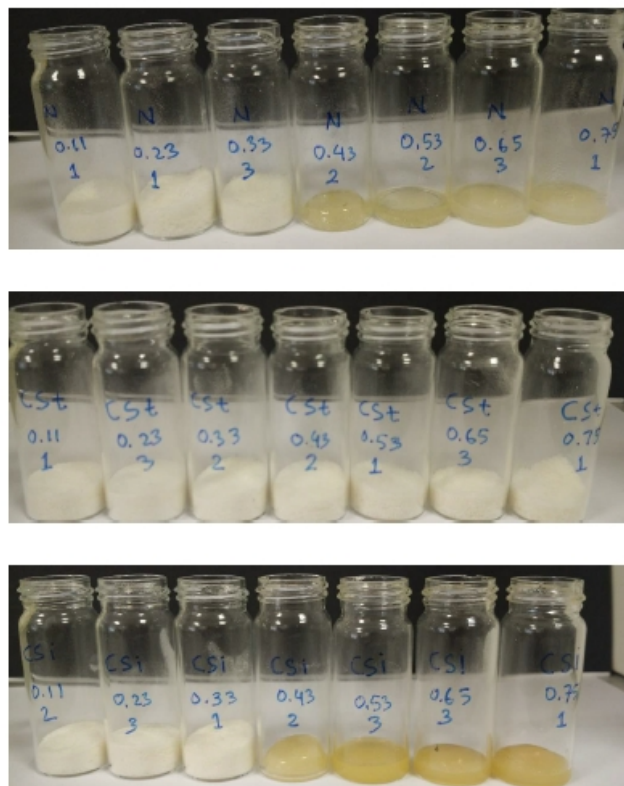


Fig. 4. Honey powder and honey powder with addition of anti-caking agent after reaching equilibrium at various water activity, from top to bottom correspond to honey powder, honey powder + 2 % calcium stearate and honey powder + 2 % calcium silicate, respectively

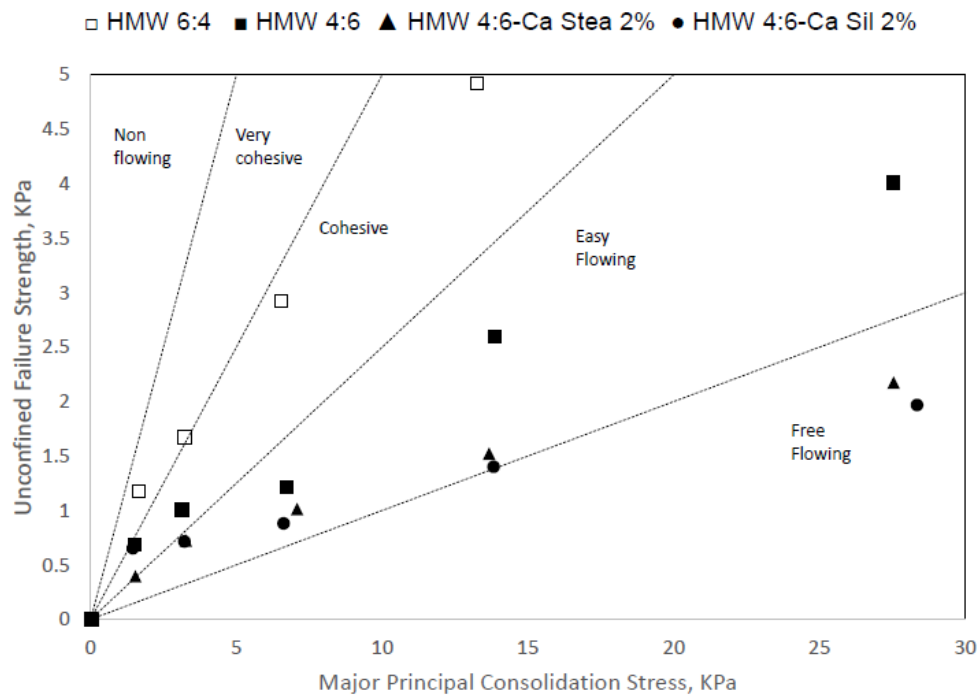


Fig. 5. The flow-ability characteristic of honey powder and honey powder with addition of anti-caking agent.

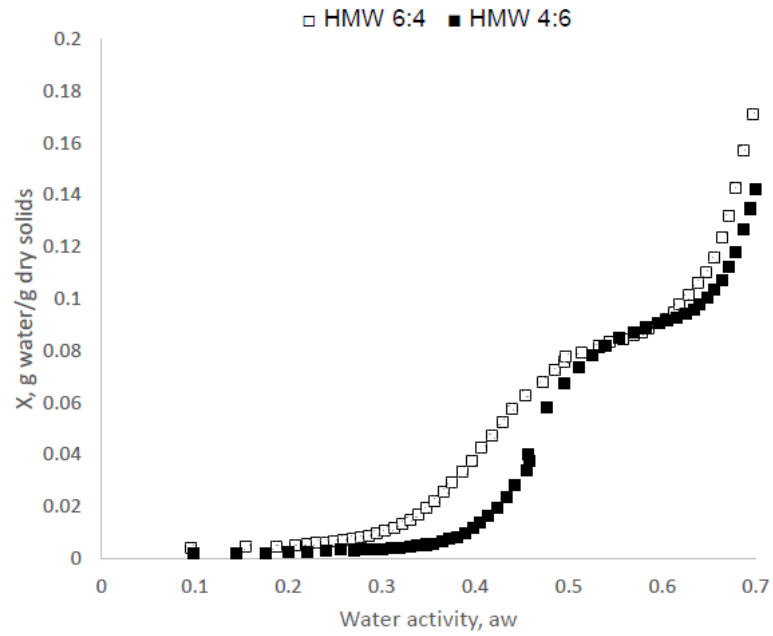


Fig. 6. Dynamic water sorption of honey powder at different ratio of maltodextrin DE 10

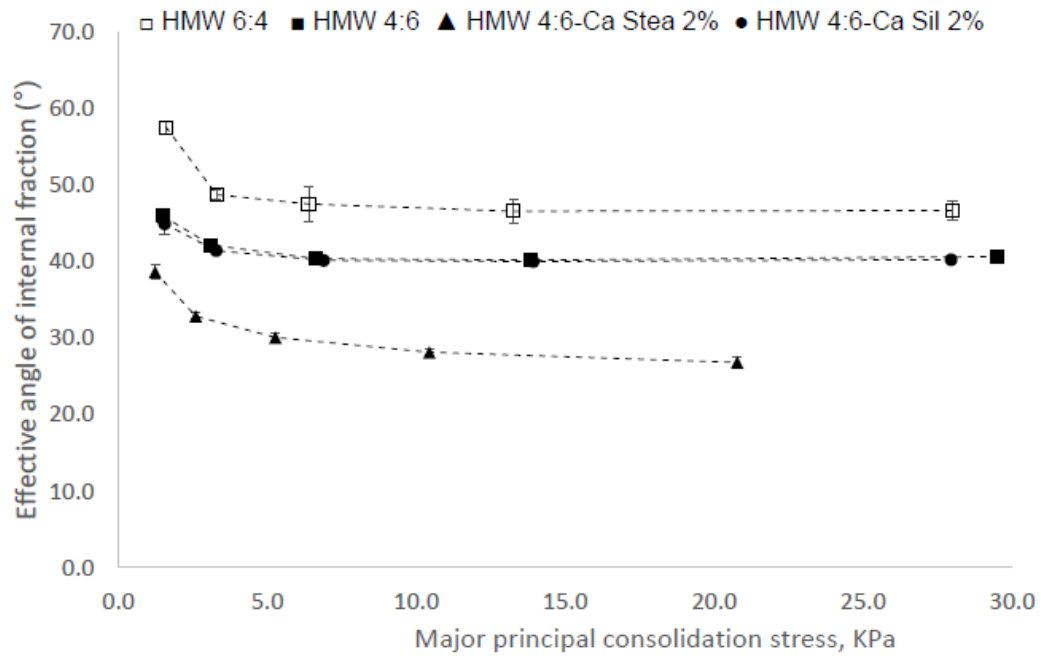


Fig. 7. Effective angle of internal friction of honey powder and honey powder with addition of anti-caking agent.

Table 1. Parameters of honey powder obtained from powder flow tester and tapped density tester.

Treatment	Powder flow-ability tester				Tapped Density (g/cm ³)		
	Flow index, ff	Density (g/cm ³)			ρ_o	ρ_t	H_R
		Initial	After Consolidation 6.5 kPa	Relative Increase			
HMW 6:4	3.04 ± 0.26	0.49 ± 0.03	0.72 ± 0.02	1.49 ± 0.03	0.58 ± 0.01	0.75 ± 0.00	1.3 ± 0.03
HMW 4:6	7.64 ± 0.43	0.59 ± 0.01	0.91 ± 0.03	1.57 ± 0.06	0.67 ± 0.01	0.81 ± 0.01	1.21 ± 0.00
HMW 4:6-Ca Stea 2 %	11.91 ± 2.55	0.66 ± 0.03	1.05 ± 0.12	1.49 ± 0.11	0.70 ± 0.01	0.85 ± 0.02	1.22 ± 0.00
HMW 4:6-Ca Sil 2 %	13.44 ± 0.38	0.64 ± 0.01	0.90 ± 0.02	1.39 ± 0.03	0.70 ± 0.00	0.81 ± 0.00	1.16 ± 0.00