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1 **EVALUATION OF A REAL-TIME TWO-STEP RT-PCR ASSAY FOR**  
2 **QUANTITATION OF CHRONIC BEE PARALYSIS VIRUS (CBPV)**  
3 **GENOME IN EXPERIMENTALLY-INFECTED BEE TISSUES AND IN**  
4 **LIFE STAGES OF A SYMPTOMATIC COLONY.**

5

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23 **Abstract**

24 A two-step real-time RT-PCR assay, based on TaqMan technology using a fluorescent  
25 probe (FAM-TAMRA) was developed to quantify Chronic bee paralysis virus (CBPV)  
26 genome in bee samples. Standard curves obtained from a CBPV control RNA and from a  
27 plasmid containing a partial sequence of CBPV showed that this assay provided linear  
28 detection over a 7-log range ( $R^2 > 0.99$ ) with a limit of detection of 100 copies, and reliable  
29 inter-assay and intra-assay reproducibility. Standardisation including RNA purification and  
30 cDNAs synthesis was also validated.

31 The CBPV TaqMan methodology was first evaluated by quantifying the CBPV genomic  
32 load in bee samples from an experimental infection obtained by topical application. Up to  
33  $1.9 \times 10^{10}$  CBPV copies per segment of insect body (head, thorax and abdomen) were  
34 revealed whereas a lower CBPV genomic load was detected in dissected organs such as  
35 mandibular and hypopharyngeal glands, brain and alimentary canal (up to  $7.2 \times 10^6$   
36 CBPV copies). The CBPV genomic loads in different categories of bees from a hive  
37 presenting the trembling symptoms typical of Chronic paralysis were then quantified.  
38 Significantly higher CBPV loads were found in guard, symptomatic and dead bees (up to  
39  $1.9 \times 10^{13}$  CBPV copies) than in forager, drones and house bees (up to  $3.4 \times 10^6$  CBPV  
40 copies). The results obtained for symptomatic or dead bees support the correlation  
41 between high CBPV genomic load and pathology expression. Moreover, the high CBPV  
42 genomic load revealed in guard bees highlights the possible pivotal role played by this  
43 category of bees in CBPV infection.

44

45 **Keywords: Chronic bee paralysis virus (CBPV), Real-time PCR, Quantitation,**  
46 **Infection dynamics, *Apis mellifera*.**

## 47 **1. Introduction**

48 *Chronic bee paralysis virus* (CBPV) is classified as a multipartite, positive-strand RNA  
49 virus. Its family and genus are currently unassigned. CBPV was first isolated in 1963  
50 (Bailey *et al.*, 1963) and characterized in 1968 (Bailey *et al.*, 1968). CBPV is the  
51 aetiological agent of an infectious and contagious disease of adult honey bees (*Apis*  
52 *mellifera* L.) known as Chronic paralysis (Ball & Bailey, 1997). Chronic paralysis is  
53 characterized by clusters of trembling, flightless, crawling bees and by individual black,  
54 hairless bees standing at the hive entrance (Bailey *et al.*, 1983). This pathology is known  
55 to induce significant losses in honey bee colonies (Bailey *et al.*, 1963; Ball & Bailey, 1997;  
56 Allen & Ball, 1996). Current diagnosis of the clinical disease is based on an AGID test  
57 (Agarose Gel ImmunoDiffusion) (Ribi re *et al.*, 2000; Ball, 1999), recently complemented  
58 by RT-PCR (Ribi re *et al.*, 2002), which has improved the detection sensitivity of CBPV,  
59 even in asymptomatic hives. Although these techniques are used to characterize the  
60 CBPV status of hives, they cannot estimate the level of CBPV infection. The quantitation  
61 of CBPV should permit a better understanding of the viral infection both in individual bees  
62 and in the hive.

63 Real-time RT-PCR detection methods have been recently developed for the detection  
64 and quantitation of bee viruses (Chen *et al.*, 2005b; Tentcheva *et al.*, 2006;  
65 Chantawannakul *et al.*, 2006). This paper describes a real-time two-step RT-PCR based  
66 on the TaqMan methodology (Heid *et al.*, 1996; Holland *et al.*, 1991; Livak *et al.*, 1995) to  
67 quantify CBPV. Standard curves from a viral RNA control and a plasmid containing a  
68 partial sequence of CBPV genome were used to obtain an absolute quantitation of CBPV.  
69 The specificity and reproducibility of the method were validated from the standard DNA  
70 curve. An experimental infection obtained by contact with purified virus was used to  
71 evaluate the method and estimate the CBPV distribution in bee tissues. The method was  
72 then applied to assess virus distribution in different categories of bees sampled from a  
73 colony with Chronic paralysis.

## 74 2. Materials and methods

75

### 76 2.1 Sample preparation, RNA extraction and cDNA synthesis

77 Adult bees were individually crushed in 1 ml of 0.01M phosphate buffer pH 6.8 in a  
78 tenbroeck grinder (Wheaton Sciences Products). The grinder was machine washed after  
79 treating with RNA and DNA decontaminant (LTK008). Hemolymph samples were  
80 collected by puncturing the intersegmental membrane at neck level, before organs  
81 dissection, using a Pasteur pipette (Fluri *et al.*, 1982) and diluted ten fold with phosphate  
82 buffer. Body segments (head, thorax, abdomen), organs dissected under binocular  
83 magnifier (mandibular and hypopharyngeal glands, brain, alimentary canal) and pooled  
84 brood samples (eggs, larvae, pupae) were washed once with phosphate buffer, then  
85 crushed in a microcentrifuge tube using a piston pellet (Eppendorf) in phosphate buffer.  
86 The homogenate was first centrifuged at 8000g for 10 min. The supernatant was  
87 recovered, centrifuged again at 8000g for 10 min. Two hundred µl of the final supernatant  
88 were then subjected to RNA extraction using the "High Pure Viral RNA Kit" (Roche  
89 diagnosis) according to the manufacturer's recommendations. First strand cDNA was  
90 synthesized from extracted RNA as described by Ribière *et al.* (2002). Five µl of the  
91 cDNA were then used as template for the CBPV TaqMan PCR.

92

### 93 2.2 Quantitative real-time PCR protocol by TaqMan assay

94

95 The primers and probe were designed by Sigma-Proligo. The chosen primer set  
96 amplifies a 101 bp fragment and is located in the putative viral RNA polymerase gene  
97 region of CBPV (Ribière *et al.*, 2002).

98 The forward primer was 5'-CGCAAGTACGCCTTGATAAAGAAC and the reverse primer  
99 was 5'-ACTACTAGAACTCGTCGCTTCG. The TaqMan probe was 5'-  
100 TCAAGAACGAGACCACCGCCAAGTTC, labelled with the fluorescent reporter dye FAM

101 (6-carboxyfluorescein) at the 5' end and with the fluorescent quencher dye TAMRA at the  
102 3' end.

103 The Platinum<sup>®</sup> Quantitative PCR SuperMix-UDG (PQM 2X, Invitrogen) was used for the  
104 amplification reaction of the TaqMan PCR. The PCR reaction contained 1X PQM, 300 nM  
105 of each primer, 200 nM of the probe, 2 mM of MgCl<sub>2</sub> (final MgCl<sub>2</sub> concentration of 5 mM)  
106 and 5 µl of standard template (RNA control or plasmid) or cDNAs in a 25 µl total reaction  
107 volume. The reaction was performed in a 25 µl SmartCycler<sup>®</sup> Tube (Cepheid,  
108 Instrumentation Laboratory). The thermal cycling conditions were 2 min at 50°C (action of  
109 uracil-N-glycosylase (UDG) to degrade any carryover DNA amplified from previous  
110 reactions), 2 min at 95°C (activation of Platinum *Taq* DNA polymerase and degradation of  
111 UDG), followed by 40 cycles consisting of denaturing at 95°C for 10 s, annealing at 50°C  
112 for 10 s and extension at 72°C for 20 s. The SmartCycler<sup>®</sup> II System (Cepheid) was used  
113 for amplification and detection.

114

115 2.3 Preparation of viral RNA and plasmid DNA standards for calibration of the CBPV  
116 TaqMan PCR assay

117 A viral RNA control was obtained from the heads of sick bees, experimentally infected by  
118 inoculation as previously described by Ribière et al (2000). Based on the extracted RNA  
119 concentration determined by UV spectrometry, homogenates were then diluted to obtain  
120  $0.8 \times 10^7$  to  $0.8$  RNA copies per µl. Two hundred µl of each dilution were subjected to  
121 RNA extraction and cDNA synthesis. A RNA standard curve for the range of  $10^8$  to  $10$   
122 RNA copies per reaction was generated by analysing 5 µl of each cDNA sample by  
123 TaqMan PCR.

124 A standard DNA curve was generated with a 3.82 kb plasmid, obtained by cloning a 800  
125 bp PCR fragment located in the putative viral RNA polymerase gene of CBPV into the  
126 pGEM<sup>®</sup>-T Easy vector (Promega). Based on the DNA concentration determined by UV  
127 spectrometry, stock solutions were prepared from serial dilutions containing  $0.2 \times 10^8$  to  $2$

128 DNA copies per  $\mu\text{l}$  in TE buffer. A standard DNA curve for the range of  $10^8$  to  $10^1$  DNA  
129 copies per reaction was generated by analysing 5  $\mu\text{l}$  of each dilution by TaqMan PCR.  
130 In both cases, the homogenate obtained from the heads of infected bees described  
131 above, was subjected to RNA extraction and cDNA synthesis and used as a positive  
132 control. A negative control (template-free) was included.

133

#### 134 2.4 Evaluation of the method

135 The two standard curves (viral RNA and plasmid DNA) were compared for the  
136 efficiencies, coefficients of correlation and results obtained for the positive control.

137 The limit of detection of the CBPV TaqMan PCR was compared with that of the  
138 qualitative PCR test previously described by Ribière *et al.* (2002), by testing the viral RNA  
139 and plasmid DNA standard prepared in dilution as detailed above. The primers were  
140 CBPV1: AGTTGTCATGGTTAACAGGATACGAG and CBPV2: TCTAATCTTAGCACGAA  
141 AGCCGAG. After conventional PCR, the amplified products (455 bp) were analysed in an  
142 ethidium bromide-stained 1.5% agarose gel.

143 The specificity of the CBPV TaqMan PCR was assessed by testing cDNAs obtained from  
144 ABPV (Acute bee paralysis virus), SBV (Sacbrood virus), BQCV (Black queen cell virus)  
145 and DWV (Deformed wing virus) samples, checked as highly positive by serial dilution in  
146 the respective specific RT-PCR tests. The primers used in the RT-PCR tests either had  
147 been previously described for ABPV (Bakonyi *et al.*, 2002) and SBV (Grabensteiner *et al.*,  
148 2001), or designed in our lab for BQCV (BQCV 3: GGTGCAAGTCTCTTCCTAG and  
149 BQCV 4: AATAACCTGAAAGGCCAAGAG) and DWV (DWV3: GGTCCGCGGCTAAGAT  
150 TGTA and DWV4: CGGCTGTTTGATGGAAGAAGTT).

151 The reproducibility of the CBPV TaqMan PCR assay was demonstrated by evaluating the  
152 intra- and inter-assay variability of the  $C_T$  values obtained after amplification of 10-fold  
153 serial dilutions of the plasmid DNA standard ranging from  $10^1$  to  $10^8$  copies per reaction.  
154 Intra-assay reproducibility was evaluated by analysing three replicates of the 10-fold  
155 serial dilutions of plasmid during the same experiment. Inter-assay reproducibility was

156 estimated by testing serial dilutions of the same standard in ten independent  
157 experiments, performed on different days.

158 The efficiency of RNA purification and cDNA synthesis was monitored by testing the  
159 positive control (RNA purification followed by cDNA synthesis) ten times and measuring  
160 the variability of the  $C_T$  values. In addition, 10 pooled bees from a field sample were  
161 crushed, divided into 10 sub-samples, and then tested ten times (RNA purification  
162 followed by cDNA synthesis) to determine sample preparation efficiency. Finally, the  
163 effect of crushing was evaluated by homogenizing healthy bees for half the normal  
164 homogenization time, checking the negativity, loading with diluted purified virus and then  
165 completing the homogenization. Ten sub-samples were tested (RNA purification followed  
166 by cDNA synthesis) to assess the effect of homogenization on the virus.

167

168 2.5 Validation of the CBPV TaqMan PCR method on experimentally- and naturally-  
169 infected bees

170 First, paralysed bees were obtained from an experimental model based on bee infection  
171 by topical application as described by Bailey et al (1983). Briefly, bees anaesthetized with  
172 carbon dioxide, were infected by contact with 3  $\mu$ l of a one thousand fold diluted viral  
173 purification on the shaved thorax (Group 1). The CBPV genomic load of this inoculum  
174 was determined. Negative controls were obtained by replacing the inoculum with  
175 physiological solution (Group 2). Trembling symptoms and mortalities were recorded daily  
176 until day 12 post-infection. Hemolymph samples were collected, at day 8 post-infection,  
177 from bees of both groups. The out-flowing hemolymph from 20 bees was pooled in chilled  
178 tubes and diluted ten fold with phosphate buffer. Four bees from each group were killed  
179 between days 8 and 9 post-contact and tissues of mandibular and hypopharyngeal  
180 glands, brain and alimentary canal were dissected. At the same time, the head, thorax  
181 and abdomen from 4 other bees of both groups were also collected.

182 Secondly, bees were collected from a single bee colony in our experimental apiary where  
183 trembling and crawling bees were observed at the hive entrance. Samples of



184 symptomatic trembling bees were taken from the flight board. The organs from 2 of these  
185 bees were dissected and hemolymph collected from 20 other bees. These samples were  
186 subjected to the same analyses as the experimentally-infected bee samples.

187 Several categories of adult bees were then sampled i) on the flight board: guards (10),  
188 pollen and nectar foragers (10), symptomatic (10) and dead bees (10) and ii) from inside  
189 the hive: drones (5), workers on a brood frame (10), workers on a honey frame (20) and  
190 emerging bees (5). Pools of pupae (5), larvae (10) and eggs (10) were also sampled.

191

## 192 2.6 Statistical analysis.

193 The CBPV genomic loads obtained from experimentally- and naturally-infected bees were  
194 analysed by the Two sample KS (Kolmogorov-Smirnov) or the Kruskal-Wallis non-  
195 parametric tests using the SYSTAT 9 computer software package (SPSS Inc.).

196 **3. Results**

197

198 **3.1 Standardisation of the CBPV TaqMan PCR assay**

199 The assay was calibrated using a viral RNA control and a plasmid DNA control as  
200 standards. The two standard curves generated from the amplification plot of a 10-fold  
201 serial dilution (Figure 1) showed a linear correlation between the  $C_T$  values and the initial  
202 RNA and DNA load over a 7-log range ( $R^2 > 0.99$ ). The slopes of the RNA and DNA  
203 standard curves were  $-0.294$  and  $-0.301$  respectively, indicating that the efficiency of the  
204 CBPV TaqMan PCR was close to 100%, the slope of a linear regression curve being  $-$   
205  $0.303$  for a theoretical 100% effective PCR (SmartCycler user's manual, Instrumentation  
206 Laboratory). No amplification was detected in the negative control.

207 The RNA concentration of the positive control, determined by spectrometry, was  $2.6 \times$   
208  $10^{10}$  CBPV RNA copies per  $\mu$ l. The estimated CBPV genomic load, according to the RNA  
209 and DNA standard curves respectively was  $1.14 \times 10^{10}$  and  $2.07 \times 10^{10}$  CBPV copies per  
210  $\mu$ l. These results confirm the accuracy of the both standard controls and validate the use  
211 of the DNA standard curve for the CBPV TaqMan PCR. The limit of detection of the  
212 CBPV TaqMan PCR was 100 CBPV genome equivalent copies, compared to  
213 conventional PCR for which the limit of detection of CBPV genome from viral RNA and  
214 plasmid DNA control was  $10^4$  copies (data not shown).

215

216 **3.2 Specificity and reproducibility of the CBPV TaqMan PCR**

217 CBPV specificity was confirmed by a Blast search on the amplicon (101 bp) generated by  
218 the TaqMan PCR. No significant similarity was found.

219 Furthermore, no amplification was detected when this TaqMan PCR was performed on  
220 cDNAs obtained from ABPV (Acute bee paralysis virus), SBV (Sacbrood virus), BQCV  
221 (Black queen cell virus) or DWV (Deformed wing virus) samples.

222 The coefficient of variation (CV) of the mean  $C_T$  values obtained for the DNA standard  
223 curve ranged from 0.13 to 1.39% within a run (intra-assay reproducibility) and from 1.21  
224 to 2.35% from run to run (inter-assay reproducibility).

225 The estimated mean CBPV genomic load of the positive control was at  $1.43 \times 10^{10}$  CBPV  
226 copies per  $\mu$ l of RNA extract, close to the concentration of  $2.6 \times 10^{10}$  CBPV RNA copies  
227 per  $\mu$ l determined by UV spectrometry. The coefficient of variation of  $C_T$  evaluated from  
228 10 independent experiments (RNA extraction followed by cDNA synthesis) was 0.99%.

229 The estimated mean CBPV genomic load from field sampled bees was  $5.9 \times 10^4$  CBPV  
230 copies per bee. The coefficient of variation of  $C_T$  evaluated from 10 independent  
231 experiments (RNA extraction from homogenized sub-samples followed by cDNA  
232 synthesis) was 0.82%. Furthermore, the  $C_T$  results obtained from crushed healthy bees,  
233 pre-loaded with purified virus (10 replicates) showed a coefficient of variation of 2.17%.

234

235 **3.3 Performance of the CBPV TaqMan PCR assay on body segments and tissues of**  
236 **experimentally- and naturally-infected bees**

237 The estimated CBPV genomic load in the inoculum applied to the bee thorax was  $1.8 \times$   
238  $10^8$  CBPV copies. Few trembling and weakening symptoms were observed 7 to 8 days  
239 post-contact in the infected bees group and all bees died 8 to 9 days post-contact. No  
240 symptoms occurred in the control group and the survival rate at day 12 was 72%.

241 The CBPV genome equivalent copy numbers (GECN) determined from samples from the  
242 infected group are given in Figure 2. The CBPV GECN in samples of mandibular and  
243 hypopharyngeal glands, brain and alimentary canal collected from 4 bees ranged from  
244  $3.7 \times 10^4$  to  $7.2 \times 10^6$  copies with respective means of  $2.5 \times 10^5$ ,  $6.8 \times 10^5$  and  $2.1 \times 10^6$   
245 copies. Higher GECN, ranging from  $4.4 \times 10^{10}$  to  $1.1 \times 10^{12}$  copies, were observed in the  
246 dissected organs of the two symptomatic bees sampled from the flight board of the hive.  
247 The CBPV GECN in samples of abdomen, thorax and head collected from four other  
248 experimentally-infected bees ranged from  $1.8 \times 10^5$  to  $1.9 \times 10^{10}$  copies with respective  
249 means of  $4.1 \times 10^8$ ,  $2.4 \times 10^9$  and  $4.9 \times 10^9$  copies. The CBPV genomic load in these

250 body segment samples was up to  $10^3$  fold higher than in the dissected tissue samples  
251 and this difference was significant ( $p=0.018$ ). However, no significant difference was  
252 observed within the groups.

253 The CBPV genomic loads in hemolymph samples collected from experimentally- and  
254 naturally-infected bees were  $2 \times 10^{10}$  and  $4.1 \times 10^9$  copies of CBPV per  $\mu\text{l}$  respectively.  
255 No CBPV genomic load was detected in any sample (organs, body sections, or  
256 hemolymph) from the control group.

257

258 **3.4 Performance of the CBPV TaqMan PCR assay on various categories of bees**  
259 **sampled from a symptomatic hive**

260 The CBPV genomic loads obtained for each category of bees from a hive showing typical  
261 symptoms of paralysis are given in Figure 3. The detected CBPV genomic load was  
262 significantly higher in guard, symptomatic and dead bees than in drones, foragers, house  
263 bees and brood collection ( $p<0.001$ ). The mean CBPV genomic load in the first category  
264 was as high as  $10^{12}$  copies per bee, and ranged from  $10^4$  to  $10^6$  copies per bee in the  
265 second category. No significant difference was observed between guard, symptomatic  
266 and dead bees whereas the CBPV GECN in forager bees was significantly different  
267 ( $p=0.012$ ) to that of house bees sampled from brood and honey frames. The CBPV  
268 genomic loads in pupae, larvae and eggs remained relatively low and did not exceed  $2 \times$   
269  $10^3$  CBPV copies per individual.

#### 270 **4. Discussion**

271 In this study, a real-time two-step TaqMan RT-PCR assay was developed to quantify the  
272 CBPV genomic load in bee samples and determine the distribution of CBPV infection  
273 both within the bees and within the hive. A TaqMan probe with primers located in the  
274 putative viral RNA polymerase gene of CBPV was used. The standard curves generated  
275 with the viral RNA control and with the plasmid containing a partial sequence from the  
276 CBPV genome showed that quantitation of this genome was linear over 7 orders of  
277 magnitude. The efficiency of both standard curves and their good correlation was  
278 confirmed. Quantitation of the positive control from CBPV-infected bee heads gave  
279 similar results for both methods compared to the value obtained by UV spectrometry.  
280 These results validate the use of the DNA standard curve to quantify CBPV in bee  
281 samples. The limit of detection of this TaqMan PCR method was  $10^2$  CBPV genome  
282 equivalent copy number (GECN), representing an improvement of the conventional PCR  
283 previously developed in our laboratory (Ribière *et al.*, 2002), for which the limit of  
284 detection was  $10^4$  CBPV copies. The intra-assay and inter-assay reproducibility studies  
285 showed the high reproducibility of the method for the standard curve (from 0.13% to  
286 1.39% and from 1.21% to 2.35% respectively), and for the efficiency of RNA purification  
287 and cDNA synthesis from the positive control (0.99%). The high reproducibility of the  
288 homogenisation technique was validated by the 10 replicates of field samples (0.82%)  
289 and loaded samples (2.17%).

290 CBPV specificity was demonstrated in relation to ABPV (Acute bee paralysis virus), SBV  
291 (Sacbrood virus), BQCV (Black queen cell virus) and DWV (Deformed wing virus)  
292 samples. These sensitivity, specificity and reproducibility results indicate that this assay  
293 can be used to quantify the CBPV genome.

294 Real-time PCR detection methods have been developed recently for the detection and  
295 quantitation of the main honey bee viruses in *Varroa destructor* (Chantawannakul *et al.*,  
296 2006), or DWV in honey bees and/or *Varroa destructor* (Chen *et al.*, 2005b; Tentcheva *et*

297 *al.*, 2006). This is the first report to describe a real-time PCR detection method for the  
298 detection and quantitation of CBPV in honey bees.

299 The performance of our CBPV TaqMan PCR assay was assessed on bees infected by  
300 topical application of the virus. Some bees only reproduced trembling symptoms of  
301 chronic paralysis during this experiment but all were dead by day 9 post-contact. An  
302 infection by intra-thoracic injection was also conducted, as described by Ribiere *et al.*  
303 (2002). In this case, all bees developed trembling symptoms from day 5 post-inoculation.  
304 We chose to analyse samples obtained by contact contamination, which corresponds to  
305 the supposed natural way of infection. Bailey *et al.* (1983) showed that CBPV could be  
306 transmitted when applied experimentally to the cuticle surface, freshly denuded of its  
307 hairs. They hypothesized that the Chronic paralysis virus was transmitted by direct  
308 contact with the epidermal cytoplasm and that, in nature, paralysis might be transmitted  
309 by contact when healthy bees are crowded with infected individuals.

310 The CBPV quantitative PCR results obtained in this model revealed high genomic loads  
311 in the head, thorax and abdomen of infected bees, reaching  $1.9 \times 10^{10}$  CBPV copies in an  
312 experimentally-infected bee head. The estimated load in the inoculum was  $1.8 \times 10^8$   
313 CBPV copies so the CBPV multiplied actively in bees following contact. This corroborates  
314 previous works that suggested the existence of a high concentration of CBPV in the head  
315 of infected bees (Bailey & Milne, 1969; Ribière *et al.*, 2002). Although results showed a  
316 significant difference between body segments and dissected organs ( $p < 0.05$ ), no  
317 significant difference was observed within the two sets of samples. Lower results were  
318 found in dissected organs with up to  $7.2 \times 10^6$  CBPV copies in the alimentary canal of one  
319 infected bee. However, higher GECN (up to  $1.1 \times 10^{12}$  copies) were revealed in the  
320 dissected organs of naturally paralysed bees.

321 Hemolymph samples from experimentally- or naturally-infected bees presented high  
322 genomic loads of up to  $2 \times 10^{10}$  and  $4.1 \times 10^9$  CBPV copies per  $\mu\text{l}$  respectively. We  
323 confirm the previous observations of Chen *et al.* (2006) who described CBPV in  
324 hemolymph, and demonstrate for the first time the presence of high CBPV loads in this

325 tissue. A high CBPV load in the hemolymph of experimentally-infected bees confirms the  
326 efficiency of CBPV infestation of bees by topical application. However, the virus loads  
327 were higher in the organs of naturally-infected bees than in experimentally-infected bees.  
328 We then validated our CBPV TaqMan methodology by conducting a second study in a  
329 symptomatic hive in our apiary, that exhibited trembling and crawling bees at the hive  
330 entrance. Various categories of bees were analysed to evaluate the CBPV genomic loads  
331 and estimate CBPV distribution within the hive.

332 The results showed that the CBPV genomic load was significantly higher in guard,  
333 symptomatic and dead bees (up to  $1.9 \times 10^{13}$  CBPV copies) than in forager, drones and  
334 workers sampled inside the hive (up to  $3.4 \times 10^6$  CBPV copies). The results obtained for  
335 symptomatic or dead bees confirm the strong correlation between high CBPV genomic  
336 load and pathology expression. Surprisingly, the highest CBPV genomic loads were not  
337 observed in the oldest bees (the foragers) but in the guard bees, which addresses the  
338 question of their role in infection. In fact, the CBPV genomic loads differed significantly  
339 between guards and foragers ( $p < 0.05$ ). It could be hypothesized that the high CBPV  
340 genomic load detected in guards sampled from the flight board of a highly symptomatic  
341 colony might be related to the higher frequency of close contacts of guards, compared to  
342 foragers, with other bees. Furthermore, the significantly lower genomic loads observed in  
343 drones and house bees sampled inside the hive, compared to forager bees ( $p < 0.05$ ), is in  
344 accordance with the fact that the disease is essentially described in older adult bees  
345 (Ball, 1999).

346 The quantitative CBPV PCR results obtained in pupae, larvae and eggs are concordant  
347 with the results obtained in brood samples by Chen et al. (2006), who hypothesized the  
348 possible transmission of CBPV from the queen to her progeny (Chen *et al.*, 2005a).  
349 However, the CBPV genomic load in these various brood samples remained relatively  
350 low, and within the limit of sensitivity of our TaqMan CBPV assay. Further investigations  
351 on the queen and her progeny will be necessary to more precisely assess the vertical  
352 transmission of CBPV and its epidemiological role.

353 In conclusion, the CBPV TaqMan RT-PCR assay developed in this study provides a  
354 sensitive, specific and reproducible method for the quantitation of CBPV genomic RNA.  
355 Preliminary assessment of the CBPV genomic loads in bee samples shows that this  
356 method can be used to monitor chronic paralysis infection in colonies. Samples of  
357 experimentally- and naturally-infected bees were studied during this work. However,  
358 CBPV can persist in apparently healthy colonies, without typical symptoms (Bailey *et al.*,  
359 1981) and these “non-apparent infections” can be detected by molecular methods  
360 (Ribière *et al.*, 2002). CBPV infection should now be studied in parallel in symptomatic  
361 and asymptomatic hives to compare the CBPV viral load, and its dynamics and  
362 distribution between individuals of the same colony. The question of correlation of the  
363 CBPV load threshold with overt disease could then be addressed and, in a broader  
364 context, the risk factors associated with the disease.



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371 the French programme for the improvement of the production and commercialisation of  
372 beekeeping products.

373 **Captions to figures**

374 **Figure 1.**

375 RNA and DNA standard curves of CBPV TaqMan PCR assay using a FAM-TAMRA  
376 labelled TaqMan probe obtained with a 10-fold serial dilution ( $10^8$ -10 copies) of a viral  
377 RNA control from the heads of sick bees (experimentally infected by inoculation) and a  
378 3.82 kb plasmid including a 800 bp fragment located in the putative viral RNA polymerase  
379 of CBPV, respectively.

380 The standard curves were obtained by linear regression analysis of the  $C_T$  measured for  
381 each amplification (*x-axis*) versus the Log copy number for each standard dilution (*y-*  
382 *axis*). The slopes of the two standard curves (RNA, -0.294 and DNA, -0.301) and the  
383 correlation coefficient are indicated (*r-squared* = 0.995 and 0.992, respectively).

384

385 **Figure 2.**

386 Evaluation of the CBPV genomic load by CBPV TaqMan PCR assay in organ and body  
387 contact samples from bees experimentally-infected by contact. The results are expressed  
388 as the mean CBPV genome equivalent copy number per organ and body segment  
389 collected from bees at 8 to 9 days post-contact. Bars represent the standard deviations.

390

391 **Figure 3.**

392 Evaluation of CBPV genomic loads by CBPV TaqMan PCR assay in various categories of  
393 bees from a symptomatic hive. The results are expressed as the mean CBPV genome  
394 equivalent copy number per bee. Bars represent the standard deviations.

Figure 1

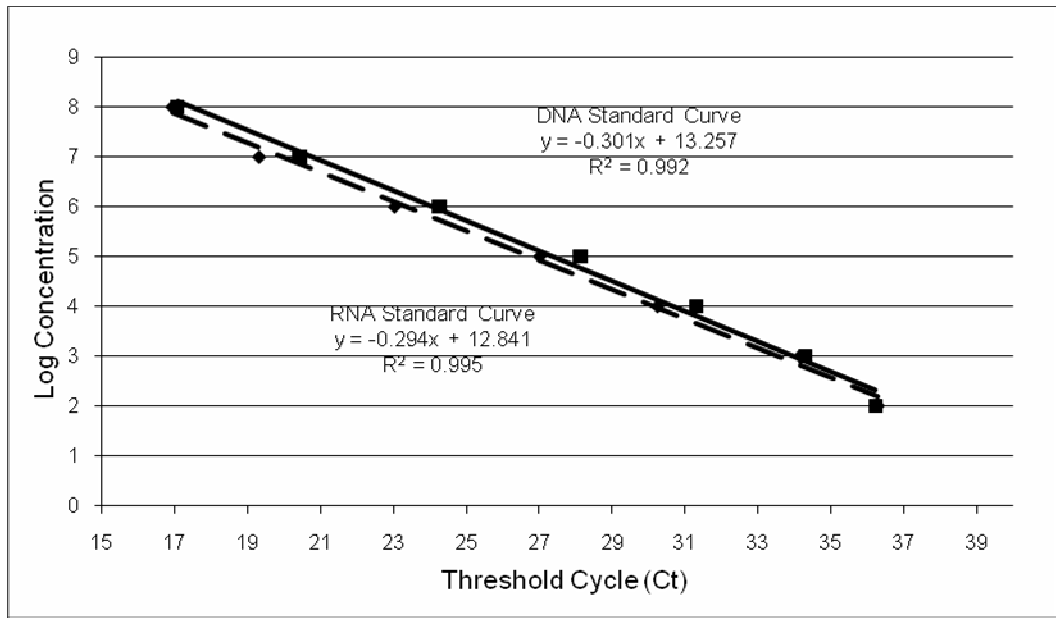


Figure 2

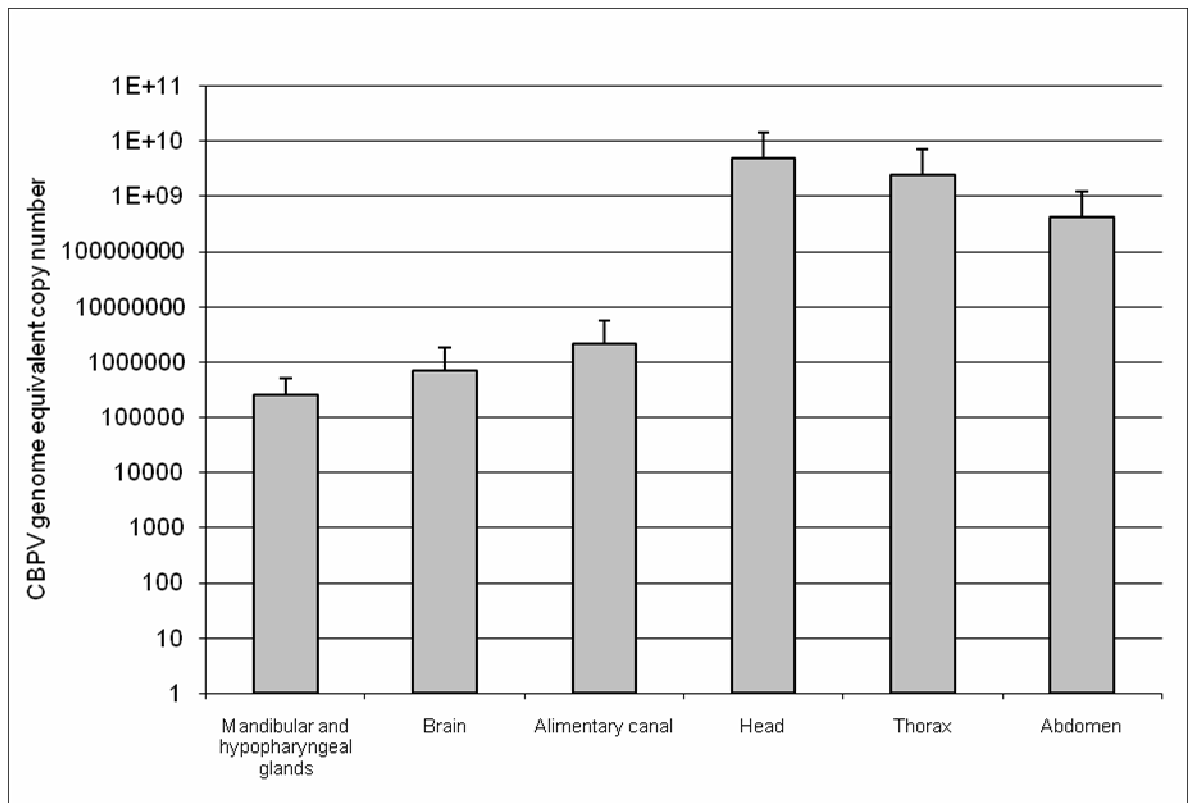
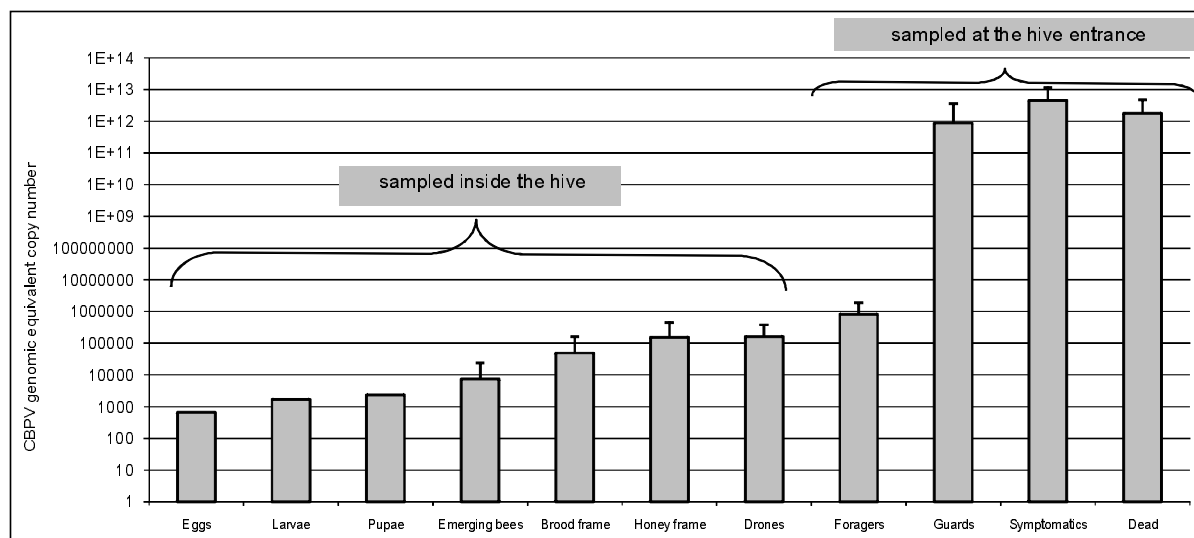


Figure 3



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