Mycological Research seal 05/5/2000

R6773-003

Running title: Longevity of conidia of *Beauveria bassiana*

The effect of environment on the longevity of conidia of *Beauveria bassiana* (Balsamo) Vuillemin

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The effect of air-dry storage environment on the longevity of conidia from seven isolates of *Beauveria bassiana* (Balsamo) Vuillemin produced at different times and locations was determined by estimating the parameters of a viability equation. Conidia were stored hermetically at six to eleven moisture contents between 2.3 and 32.0 % with one (50 ± 0.5 °C) to five constant temperatures (10, 20, 30, 40 and 50 ± 0.5 °C) for various periods up to 372 d and then tested for viability. All isolates behaved similarly (P> 0.25) in terms of the relative effect of moisture content (C_W) and temperature (C_H and C_Q) on conidia longevity; common values were C_W=3.05 (SE=0.07), C_H = 0.0293 (SE= 0.0078), and C_Q = 0.00081 (SE= 0.00011). Estimates of the low-moisture-content limit to the negative logarithmic relation between conidia moisture content and longevity were 4.6 and 5.0 % at 50 °C and 40 °C, respectively, for isolate I98-1140ss, and 5.2 and 5.1 % moisture content, respectively, for isolate

I97-1111. Absolute longevity (K_E) varied considerably ($P< 0.005$) among isolates, even within an isolate when conidia were produced at different locations. Among the eight samples of seven isolates, two cohorts were identified with respect to K_E ($P< 0.005$): conidia of three isolates which were produced at Ascot had a common estimate of K_E of 6.696 (SE= 0.170), whereas those produced at Nairobi or Carolina provided a lower estimate (6.203, SE= 0.029). This difference in K_E means that for any given viability period in any given environment, the conidia produced in Ascot provided about three times the longevity of the other samples.

INTRODUCTION

Entomopathogenic fungi, particularly *Metarhizium* and *Beauveria* spp., have been tested as promising biopesticides in integrated pest management (IPM) systems (Gillespie, 1988). Various strains of *Beauveria bassiana* (Balsamo) Vuillemin have been demonstrated to be virulent to the desert locust *Schistocerca gregaria* Forskål (Prior *et al.*, 1992), cocoa weevil *Pantorhytes plutus* Oberthür (Prior, Jollands & le Patourel, 1988), larger grain borer *Prostephanus truncatus* Horn of maize (*Zea mays* L.) and cassava (*Manihot esculenta* Crantz) (Smith *et al.*, 1999), and other grain borers such as *Sitophilus oryzae* L., *Rhyzopertha dominica* F. and *Tribolium castaneum* Herbst (Rice & Cogburn, 1999).

For effective biological control, conidia of entomopathogenic fungi must retain high viability and virulence (McClatchie *et al.*, 1994). The conidia must, therefore, have predictable shelf lives if they are to be reliable biopesticides.

The survival of conidia of *Metarhizium anisopliae* var. *acridum* (revised recently from *Metarhizium flavoviride* W. Gams & J. Rozsypal by Driver, Milner &

Trueman, 2000) can now be estimated using mathematical models driven by conidia moisture content and temperature, even in environments where temperature fluctuates (Hong, Ellis & Moore, 1997; Hong *et al.*, 1998; Hong, Jenkins & Ellis, 1999). Moreover, this approach can be applied over wide geographic regions by combining with spatial meteorological data and models which quantify the effect of ambient temperature and relative humidity on equilibrium conidia moisture content (Hong *et al.*, 2000). The viability equations developed for conidia of several entomopathogenic and plant pathogenic fungi (Hong *et al.*, 1997, 1998, 1999) comprise two basic equations. The first is:

$$v = K_i - p/\sigma \quad (1)$$

where v is probit percentage viability, σ is the standard deviation of the frequency distribution of conidia deaths in time (p, d), and K_i is the intercept (i.e. an estimate of v at zero time).

Relations between conidia longevity (σ), storage temperature (t, °C) and moisture content (m, % w.b.) are described by the equation

$$\log_{10}\sigma = K_E - C_W\log_{10}m - C_Ht - C_Qt^2 \quad (2)$$

where K_E, C_W, C_H, and C_Q are constants. The constant K_E, "absolute longevity", denotes the extrapolated value of $\log_{10}\sigma$ at 1 % moisture content (because $\log_{10}1 = 0$) and 0 °C. C_W describes the relative effect of moisture content on longevity. It is the gradient of the negative logarithmic relation between conidia moisture content (m) and longevity (σ). The combined effect of the constants C_H and C_Q describes the response of conidia longevity (σ) to temperature (t).

At a single temperature, eqn (2) can be simplified to

$$\log_{10}\sigma = K - C_W\log_{10}m \quad (3)$$

where

$$K_E = K + C_H t + C_Q t^2 \qquad (4)$$

Within these equations, differences among batches of conidia (principally in initial viability) are accounted for by variation in the value of the constant K_i. Comparison among different batches of conidia of *Metarhizium anisopliae* var. *acridum* that we have produced using the same protocol has shown differences in K_i and imply that the values of the constants K_E, C_W, C_H, and C_Q are unaffected (Hong *et al.*, 1999). That is, the results have shown good repeatability. Note, however, that different conidia production practices can affect both K_i and σ (Hong, Jenkins & Ellis, 2000). Such variation in σ implies that one or more of the constants K_E, C_W, C_H, and C_Q may be affected by conidia production practices.

The above mathematical model was developed with survival data for stored conidia of *Beauveria bassiana* also (Hong *et al.*, 1997). However, the original data for this species was limited in range and the environments were (relatively) uncontrolled (e.g. temperature ± 4 °C).

The objectives of the present investigation were to estimate the value of the parameters of the viability equation (K_E, C_W, C_H and C_Q) for *Beauveria bassiana* in order to test the following null hypotheses: samples/isolates of *Beauveria bassiana* of different provenances do not differ in terms of (i) C_W, (ii) C_H and C_Q, (iii) K or K_E. We also determine whether or not two samples of the same isolate produced at different times and locations provide consistent estimates of these constants, and estimate the low moisture content limit to negative logarithmic relations between conidia moisture content and longevity.

MATERIALS AND METHODS

Eight samples of seven isolates of *Beauveria bassiana* (Balsamo) Vuillemin were obtained (Table 1). Conidia of the three isolates I97-1119, I98-1140ss and I97-1111 were produced at CABI Bioscience (Ascot, UK) in the two-stage system described by Jenkins *et al.* (1998) for *Metarhizium anisopliae* var. *acridum* (and described in greater detail by Hong *et al.*, 1998, Hong, Jenkins & Ellis, 1999). Conidia were dried over silica gel at room temperature (20-25 °C) to 5-6 % moisture content and then stored hermetically at 5-7 °C. Conidia of the four isolates I97-116a, I96-1020, I97-1111 and KE28 were produced at CABI African Regional Centre (Nairobi, Kenya) by the same general method. The samples were dried to 5-6 % moisture content with silica gel, before placing in sealed bottles. Conidia of the isolate JABB 9908-1330 were produced by JABB of the Carolinas Inc. (Carolina, USA). On receipt at Ascot, this sample had a moisture content of 12.4 % and contained some substrate particles. It was passed through a dual cyclone spore extraction device and dried over silica gel to 5-6 % moisture content.

All eight samples were brought to Reading where equilibrium relative humidity of the sample was first determined using a Novasina Humidat IC1 (Zürich). The samples were then hermetically sealed in laminated aluminium foil packets and stored at 0 °C until investigations began (approximately 1-2 weeks).

<Table 1 near here>

In order to determine longevity, the eight samples of conidia were removed from storage at 0 °C and were dried or humidified to between six and eleven different moisture contents (depending upon sample size) between 2.3 and 32 % using saturated solutions of ammonium sulphate ($(NH_4)_2SO_4$, 80 % rh), sodium chloride (NaCl, 75 % rh), sodium nitrite ($NaNO_2$, 65 % rh), calcium nitrate ($Ca(NO_3)_2$, 52 % rh), potassium nitrite (KNO_2, 45 % rh), magnesium chloride ($MgCl_2$, 32.8 % rh), potassium acetate (CH_3COOK, 20 % rh), lithium chloride (LiCl, 13.5 % rh) and silica gel for samples with moisture contents below 5 %, all at 20 °C. The samples were then each sealed in a laminated aluminium foil packet and maintained at 0 °C for three days before conidia moisture content was determined. Two 0.7 g samples of conidia were dried in a mechanically-ventilated oven at 103 ± 2 °C for 17 h and loss in weight on drying determined. Conidia moisture contents were calculated on the fresh weight basis (w.b.).

For each storage environment, 11 sub-samples of conidia (each of 0.4 g) were hermetically sealed in laminated aluminium foil packets (10 x 15 mm). These sub-samples were stored in incubators maintained at either 50 ± 0.5 °C or 10, 20, 30, 40 and 50 ± 0.5 °C, depending upon the isolate (Fig. 1). Temperature in each incubator was monitored and logged every 20 s using a data logging system (TempScan/1000A, IOtech, Ohio, USA), and the mean temperature during experimental storage calculated. Samples were removed from storage at intervals ranging from 10 min to 35 d, for periods up to 372 d, depending upon the environment.

All samples, including controls (i.e. not stored), for each treatment were tested for viability by assessing ability to germinate. The foil packet containing conidia was opened fully and floated on a plastic tray over water in a closed container for at least 30 min in order to re-humidify the conidia to *circa* 15 % moisture content before the germination test, in order to avoid imbibition damage (Moore, Langewald & Obognon, 1997). The conidia were then suspended in 10 ml of Shellsol T (Alcohols Ltd., Bishops Stortford, Herts.) in a capped plastic tube and vortexed thoroughly. A concentration of *ca* 1×10^6 conidia ml^{-1} (to avoid inhibition or promotion of germination by extreme conidia densities) was used. The suspensions were then treated in an ultrasonic bath (Branson 2200, Connecticut, USA) for 3 min to break up any conidial chains. Using a microspatula, a small aliquot (approximately 30 ± 5 µl) of the sonicated suspension was spread evenly over the surface of Sabouraud Dextrose Agar (SDA) (Oxoid/Unipath, Basingstoke, Hants.) in 50 mm-diameter Petri dishes. All media was used within one week of preparation. Three replicate dishes were prepared for each sample. Inoculated Petri dishes were placed in an incubator maintained at 27 °C for 24 h, a temperature recommended by Fargues *et al.* (1997). This is very similar to the standardized protocol used to estimate the viability of conidia of *Metarhizium anisopliae* var. *acridum* (e.g. Hong *et al.*, 1998, 1999; Jenkins *et al.*, 1998). Germination of conidia was then assessed using an Olympus CX40 compound microscope with bright field illumination at x300 magnification. For each Petri dish, all conidia within each field of view were counted. Linear transects from one field of view to another were made until more than 300 conidia had been counted. Conidia were considered to have germinated if the germ tube was equal in length or greater than the diameter of the conidia.

Conidia survival curves were then fitted to the observations by probit analysis using GLIM (Baker & Nelder, 1978) in accordance with eqn (1).

RESULTS

In accordance with eqn (1), for each sample negative cumulative normal distributions constrained to a common origin were fitted to the conidia survival data at all moisture contents and temperatures by probit analysis. The constraint of a common origin within a sample among storage environments did not increase error significantly ($P > 0.10$). The resultant estimates of K_i for each sample are shown in Table 2, while those for σ are shown in Fig. 1. The lowest estimate of K_i was 0.409 (equivalent to 66 % initial germination) for isolate I98-1140ss and the highest estimate was 2.202 (equivalent to 98.6 % initial germination) for isolate I97-1111 (Table 2).

<Table 2 near here>

Effect of storage moisture content and temperature on conidia longevity

Regression analyses were carried out in several steps. First, for each sample the relation between conidia longevity (*σ*) and moisture content between 5 and 32.0 % at 50 °C was analysed. The results showed a negative logarithmic relation between conidia longevity and moisture content (solid circles in Fig. 1). Estimates of *K* varied between 2.440 (SE= 0.260) and 3.310 (SE= 0.353), and those of C_W between 2.82 (SE= 0.25) and 3.19 (SE= 0.24) among the eight samples (Table 2).

Secondly, these observations were subjected to comparison of regression. This analysis showed that all samples had a common slope (C_W= 3.05, SE= 0.07, $P>$ 0.25), but the value of the intercept (*K*) varied considerably ($P<$ 0.005) from 2.599 (SE = 0.068) to 3.235 (SE= 0.090).

Thirdly, observations for the two different samples of isolate I97-1111 stored at 50 °C, one produced at Ascot (Fig. 1c) and one at Nairobi (Fig. 1g), were compared. The samples provided a common estimate of C_W (3.07, SE= 0.13, $P>$ 0.25), but differed in the intercept *K* significantly ($P<$ 0.005): *K* = 2.837 (SE= 0.144) for the Nairobi sample, but *K* = 3.152 (SE= 0.065) for the Ascot sample.

<Fig. 1 near here>

Fourthly, for each of the four isolates I97-1119, I98-1140ss, I97-1111 (produced at Ascot) and I97-1116a observations for longevity at all storage temperatures (i.e. 10, 20, 30, 40 and 50 °C) and moisture contents between 5 and 32.0 % were analysed. Negative logarithmic relations between conidia longevity and moisture content were detected at each temperature and longevity increased the cooler the temperature (Figs 1a –1d). Estimates of the parameters of the viability equation for each individual sample are shown in Table 2 (middle row). Among these four isolates, estimates of K_E varied between 6.393 and 6.836, C_W between 2.93 and 3.36, C_H between 0.0194 and 0.0365 and C_Q between 0.00072 and 0.00097 (Table 2). While the effect of temperature on conidia longevity was significant ($P< 0.005$) in each of the four samples, in some samples both components of the combined temperature term ($- C_H t - C_Q t^2$) were significant (e.g. I98-1140ss), whereas in other samples they were not (e.g. I97-1119). The latter is presumably the result of a restricted range of storage temperature. The models fitted by the separate analyses of each sample are shown as broken lines in Figs 1a-1d.

Fifthly, all observations of longevity for all eight samples at moisture contents between 5 and 32.0 % at all temperatures (10 to 50 °C) were analysed in a combined data set. Comparison of regressions showed that all samples had a common value of C_W (3.04, SE= 0.07, $P> 0.10$), C_H (0.0295, SE= 0.0077, $P> 0.25$) and C_Q (0.00081, SE= 0.00011, $P> 0.25$), but K_E varied considerably ($P< 0.005$) between extremes of 6.085 (SE= 0.068) and 6.688 (SE= 0.173).

Finally, we examined the effect of conidia production location on K_E. Comparison of regressions showed two discrete cohorts of isolates ($P< 0.005$): the three samples produced at Ascot provided a common estimate of K_E (6.696, SE= 0.170, $P> 0.05$), while the five samples produced at Nairobi or Carolina provided a lower common estimate for K_E (6.203, SE= 0.029, $P> 0.05$) (Table 2). Further analysis with K_E constrained to these values confirmed that all eight samples provided a common estimates of C_W (3.05, SE= 0.07, $P> 0.10$), C_H (0.0293, SE= 0.0078, $P> 0.25$), and C_Q (0.00081, SE= 0.00011, $P> 0.25$) (Table 2).

Determination of the low-moisture-content limit

The longevity of conidia of *Beauveria bassiana* did not increase further when storage moisture content was reduced below about 5 % for the two isolates (I98-1140ss and I97-1111) for which observations were available at such low moisture contents (open symbols in Figs 1b and 1c). In order to determine the low-moisture-content limit to the negative logarithmic relation between conidia longevity and moisture content for isolate I98-1140ss, the observations at all 10 moisture contents at 50 °C were first analysed within a single data set in accordance with eqn (3) by linear regression analysis. The data was subsequently analysed iteratively in two separate sets with progressively more estimates of σ being apportioned to the lower moisture content set. Total residual deviance was minimised when the two lowest moisture content observations were excluded from the linear regression (open circles in Fig. 1b). The negative logarithmic relation between σ and moisture content between 5.4 and 27.3 % at 50 °C was significant (P<0.005, r^2= 0.983, dashed line in Fig. 1b). In contrast, σ did not differ at moisture contents of 3.4 and 4.1 % at 50 °C, and a horizontal line is shown in Fig. 1b below 5 %. The two lines intersect at 4.6 %, which provides the estimate of the low-moisture-content limit to the negative logarithmic relation between conidia longevity and moisture content at 50 °C. Similarly, at 40 °C the lines intersect at 5.0 % moisture content. Similar estimates of m_c were obtained for isolate I97-1111 (Table 3).

<Table 3 near here>

DISCUSSION

Estimates of the low-moisture-content limit to negative logarithmic relations between conidia longevity and moisture content for isolates I98-1140ss and I97-1111 varied only between 4.6 and 5.2 % (Table 3). These conidia moisture contents are in equilibrium with about 11-14.0 % rh at 20 °C (Hong *et al.*, 2000). These values are similar to those of 10.7 % rh at 20 °C for conidia of *Metarhizium anisopliae* var. *acridum* (Hong *et al.*, 1998), 11.9 % rh at 20 °C for pollen of *Typha latifolia* (Hong *et al.*, 1999) and 10-12 % rh at 20 °C for seeds of several orthodox species (Ellis, Hong & Roberts, 1989; Ellis *et al.*, 1996). This confirms a considerable economy of nature for the anhydrous biology of such contrasting propagules.

The eight samples of seven different isolates of *Beauveria bassiana*, produced in different laboratories at different times, behaved similarly in terms of the relative effect of moisture content (C_W) and temperature (C_H and C_Q) on conidia longevity. That is all samples examined provided common estimates of C_W, C_H, and C_Q. The common estimate of C_W (3.05, SE= 0.07) for conidia of *Beauveria bassiana* is very similar to that for conidia of *Metarhizium anisopliae* var. *acridum* (C_W = 3.06, SE= 0.24; Hong *et al.*, 1998). The current estimates of C_H (0.0293, SE= 0.0078) and C_Q (0.00081, SE= 0.00011) for *Beauveria bassiana* differ somewhat from those for *Metarhizium anisopliae* var. *acridum* (C_H = 0.0176, SE= 0.0013; C_Q = 0.000703, SE= 0.000019; Hong *et al.*, 1998). Note, however, that C_H and C_Q are comparatively difficult to estimate from a limited range of storage temperatures and the observations for *Metarhizium anisopliae* var. *acridum* were limited to only the three temperatures 30, 40 and 50 °C (Hong *et al.*, 1998). Indeed, the estimates for *Beauveria bassiana* are similar to those for pollen of *Typha latifolia* L. (C_H = 0.0304, SE= 0.008; C_Q = 0.00065, SE= 0.00016; Hong *et al.*, 1999), and orthodox seeds (C_H = 0.0329, SE= 0.0017; C_Q = 0.00048, SE= 0.00002; Dickie *et al.*, 1990). Again, this points to the economy of nature.

Comparison of the estimates of K at 50 °C for the eight samples of *Beauveria bassiana* (K = 2.44-3.31, Table 2) with that for *Metarhizium anisopliae* var. *acridum* (also at 50 °C) (K= 3.662, SE= 0.247; Hong *et al.*, 1998) shows that conidia of *Beauveria bassiana* were considerably shorter lived than those of *Metarhizium anisopliae* var. *acridum* (a difference of 0.301 in K is a doubling of longevity).

Moreover, the variation in absolute longevity among samples within *Beauveria bassiana* was systematic. Comparison of K at 50 °C for isolate I97-1111 provided a greater estimate for conidia produced at Ascot than in Nairobi (Table 2). Similarly, estimates of K_E were greater for the samples produced at Ascot (6.696) than those produced elsewhere (6.203). Since an increase of 0.3 in K_E (or in K) doubles longevity, this difference is dramatic and worthy of further investigation. Given the evidence in *Metarhizium anisopliae* var. *acridum* that subsequent longevity is affected considerably by aspects of the conidia production environment, such as duration of incubation and rate of drying (Hong *et al.*, 2000), we suggest that greater attention must be paid to the conidia production method of entomopathogenic fungi in order to maximise their effectiveness as biopesticides. Indeed, the fact that the conidia production methods at CABI Nairobi and CABI Ascot were apparently similar, but subsequent conidia longevity so different, emphasises that even minor changes in production methodology can have significant and substantial effects on the quality of the conidia produced.

ACKNOWLEDGEMENTS

This research was funded by the Crop Post-Harvest Research Programme of the Department for International Development of the United Kingdom. However, the Department for International Development can accept no responsibility for any information provided or views expressed. We thank JABB of the Carolinas Inc. (USA) and CABI African Regional Centre (Nairobi, Kenya) for providing conidia.

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CAPTIONS TO FIGURE

Figure 1. Relations between conidia longevity (σ) and moisture content (%, w.b.) of conidia of eight samples from seven isolates of *Beauveria bassiana* produced at three locations (Table 1), stored hermetically at 50 (●), 40 (■), 30 (▲), 20 (▼) and 10 ± 0.5 °C (◆). The broken lines (......) were fitted separately for each isolate to observations between about 5 and up to 32 % moisture content (denoted by solid symbols) with either 50 °C or all temperatures between 10 and 50 °C. The solid lines (——) represent models with common values of C_W, C_H and C_Q for all eight samples and two values of K_E for samples produced at Ascot or elsewhere (see text). The low-moisture-content limits to the relations were determined by intersection between lines (– – –) fitted to the two separate sets of observations denoted by the open and solid symbols (see text). The parameters of the fitted lines are shown in Tables 2 and 3.

Table 1. Information on the samples of conidia of *Beauveria bassiana* provided for this investigation

	Isolate	Origin	Location of conidia production	Moisture content (%, w.b.) and equilibrium relative humidity (%) when received at Reading	Initial viability (%)	Date storage investigation began
1	I97-1119 (KE33)	Kenya	Ascot	5.0 (13.8)	96	10 June1998
2	I98-1140ss	Afghanistan	Ascot	6.0 (18.8)	80	4 Jan.1999
3	I97-1111 (KE29)	Kenya	Ascot	5.3 (14.5)	93	21 Dec.1998
4	I97-1116a (KE26)	Kenya	Nairobi	5.5 (15.6)	82	26 Apr.1999
5	JABB-9908-1330	Unknown	Carolina	5.0 (13.6)	81	30 July1999
6	I96-1020 (KE06)	Kenya	Nairobi	4.6 (10.5)	97	30 July1999
7	I97-1111 (KE29)	Kenya	Nairobi	4.5 (10.0)	96	30 July1999
8	KE28	Kenya	Nairobi	4.8 (11.3)	77	30 July1999

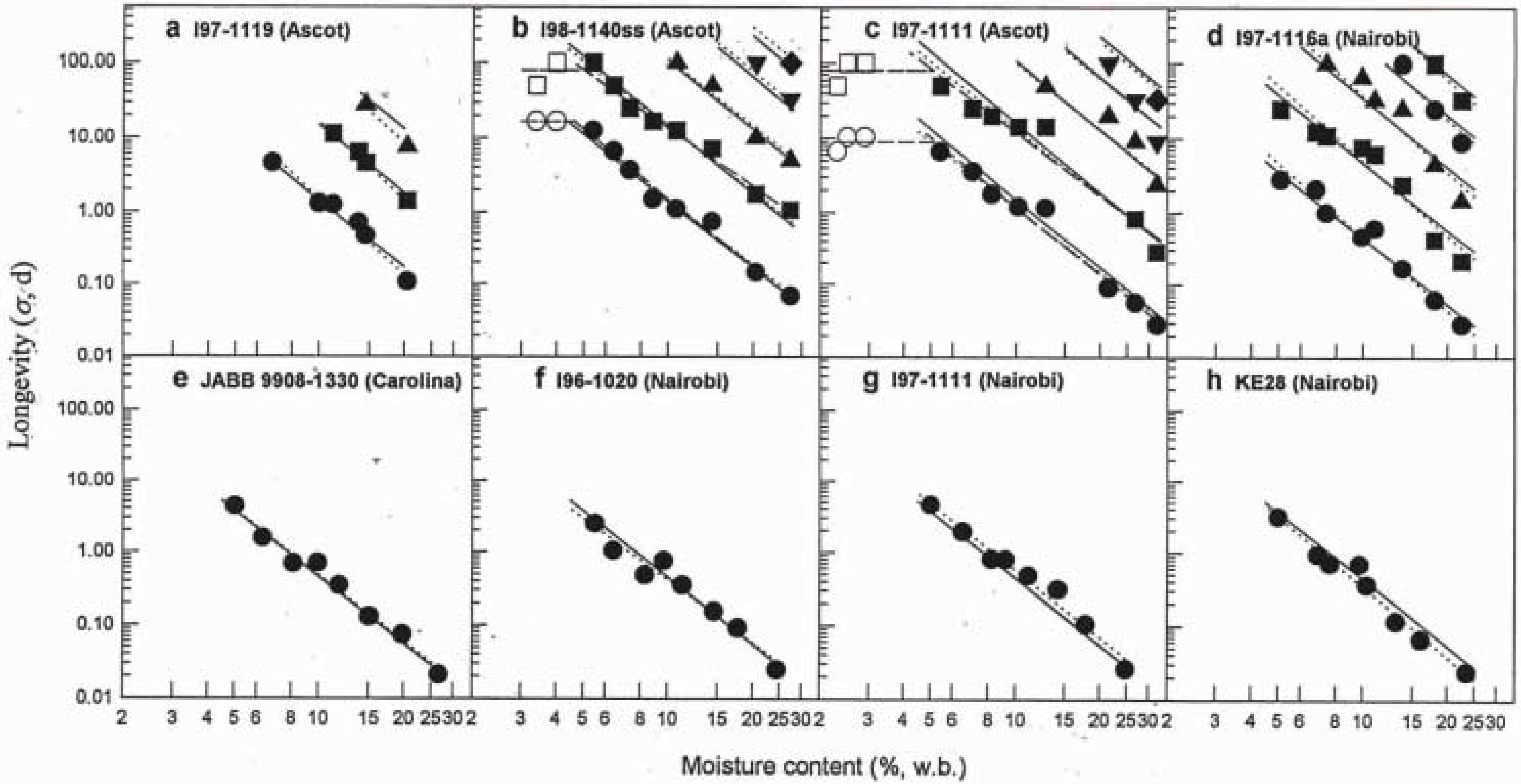
Table 2. Estimates of the parameters of the viability equations describing relations between conidia longevity (σ), temperature and moisture content during storage for eight samples of conidia of *Beauveria bassiana* (seven isolates produced at three locations). Only observations for longevity between 5 and 32 % moisture content were analysed. For each isolate, the estimates of K and C_W shown in the top row were determined separately for the longevity (σ) of conidia stored at 50 °C only. The estimates of K_E, C_W, C_H and C_Q shown in middle row were determined separately for each of the first four isolates (1-4) for longevity at all temperatures, while those shown in the bottom row were determined for the combined data set (all eight samples) constrained to common values of C_W, C_H and C_Q, and two common values for K_E (see text).

	Isolate (Production site)	K_i (SE)	K (SE)	K_E (SE)	C_W (SE)	C_H (SE)	C_Q (SE)
1	I97-1119 (Ascot)	1.308 (0.005)	3.310 (0.353)	-	3.15 (0.32)	-	-
				6.836 (0.236)	3.33 (0.25)	0.0284 (0.0590)	0.00076 (0.00071)
				6.696 (0.170)	3.05 (0.07)	0.0293 (0.0078)	0.00081 (0.00011)
2	I98-1140ss (Ascot)	0.409 (0.003)	3.290 (0.175)	-	3.11 (0.17)	-	-
				6.739 (0.265)	2.94 (0.11)	0.0365 (0.0116)	0.00072 (0.00022)
				6.696 (0.170)	3.05 (0.07)	0.0293 (0.0078)	0.00081 (0.00011)

3	I97-1111 (Ascot)	2.202 (0.005)	3.172 (0.224)	-	3.09 (0.20)	-	-
				6.393 (0.434)	2.93 (0.16)	0.0194 (0.0199)	0.00097 (0.0008)
				6.696 (0.170)	3.05 (0.07)	0.0293 (0.0078)	0.00081 (0.00011)
4	I97-1116a (Nairobi)	1.166 (0.004)	2.859 (0.250)	-	3.19 (0.24)	-	-
				6.549 (0.346)	3.36 (0.18)	0.0282 (0.0143)	0.00084 (0.00021)
				6.203 (0.029)	3.05 (0.07)	0.0293 (0.0078)	0.00081 (0.00011)
5	JABB 9908-1330 (Carolina)	0.674 (0.007)	2.690 (0.173)	-	3.00 (0.16)	-	-
				-	-	-	-
				6.203 (0.029)	3.05 (0.07)	0.0293 (0.0078)	0.00081 (0.00011)
6	I96-1020 (Nairobi)	1.723 (0.008)	2.440 (0.260)	-	2.82 (0.25)	-	-
				-	-	-	-
				6.203 (0.029)	3.05 (0.07)	0.0293 (0.0078)	0.00081 (0.00011)
7	I97-1111 (Nairobi)	1.591 (0.007)	2.808 (0.205)	-	3.05 (0.20)	-	-
				-	-	-	-
				6.203 (0.029)	3.05 (0.07)	0.0293 (0.0078)	0.00081 (0.00011)
8	KE28 (Nairobi)	0.781 (0.006)	2.737 (0.230)	-	3.19 (0.22)	-	-
				-	-	-	-
				6.203 (0.029)	3.05 (0.07)	0.0293 (0.0078)	0.00081 (0.00011)

Table 3. Estimates of the low-moisture-content limit (m_c) to negative logarithmic relations between conidia longevity and moisture content in two samples of *Beauveria bassiana*.

Isolate	Temperature (°C)	Low moisture content range $\log_{10}\sigma$ (SE)	Greater moisture content range K (SE)	C_W (SE)	(m_c) (± SE)
I98-1140ss	40	1.900 (0.100)	3.702 (0.169)	2.567 (0.154)	5.0 (4.3-5.9)
	50	1.222 (0.000)	3.290 (0.175)	3.105 (0.165)	4.6 (4.1-5.2)
I97-1111	40	1.900 (0.100)	3.885 (0.332)	2.802 (0.299)	5.1 (4.0-6.6)
	50	0.951 (0.063)	3.172 (0.224)	3.092 (0.196)	5.2 (4.5-6.1)


a I97-1119 (Ascot)
b I98-1140ss (Ascot)
c I97-1111 (Ascot)
d I97-1116a (Nairobi)
e JABB 9908-1330 (Carolina)
f I96-1020 (Nairobi)
g I97-1111 (Nairobi)
h KE28 (Nairobi)
Longevity (σ, d)
Moisture content (%, w.b.)