Exoskeletal microstructure and tensile behavior of the acorn weevil rostrum

M. Andrew Jansen,[1,*] Jason Williams,[2] Nikhilesh Chawla,[2] and Nico M. Franz[1]
[1]*School of Life Sciences, Arizona State University, Tempe, AZ 85287, USA*
[2]*School for Engineering of Matter, Energy, and Transport, Arizona State University, Tempe, AZ 85287, USA*
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I. MICROSTRUCTURE OF THE *CURCULIO* ROSTRUM

II. FORCE-CONTROLLED LOADING TO FRACTURE

III. LOAD CYCLING OF *CURCULIO CARYAE*

IV. FRACTOGRAPHY OF TEST SPECIMENS

V. CONCLUSIONS

VI. METHODS

Methods, including statements of data availability and any associated accession codes and references, are available in the online version of this paper.

REFERENCES

[1] Leslie Lamport, *LaTeX: a document preparation system*, Addison Wesley, Massachusetts, 2nd edition, 1994.

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AUTHOR CONTRIBUTIONS

Andrew Jansen: Conducted sectioning and staining, microscopy and imaging, tensile and fatigue testing, statistical analysis, and participated in manuscript preparation.

Jason Williams: Conducted tensile and fatigue testing, participated in manuscript preparation.

Nikhilesh Chawla: Facilitated microscopy, tensile and fatigue testing, and participated in manuscript preparation.

Nico Franz: Facilitated specimen acquisition and imaging, participated in manuscript preparation.

ADDITIONAL INFORMATION

Supplementary information is available in the online version of the paper. Reprints and permissions information is available online at www.nature.com/reprints. Correspondence and requests for materials should be addressed to M.A.J.

COMPETING FINANCIAL INTERESTS

The authors declare no competing financial interests.

* corresponding author, email: majanse1@asu.edu

METHODS

Histological sectioning

Tensile and fatigue testing

Specimen imaging and microscopy

Statistical analysis

General approach To explore the relationships between the composite structure and mechanical properties of the cuticle, we fit phylogenetic linear mixed-effects models to the data using maximum likelihood estimation. In order to control for phylogenetic non-independence in the data, we included the species of each specimen as a random effect in all models. We also allowed for correlation in the error term of the models, as specified by a variance-covariance matrix generated from a Brownian motion model of trait evolution along the phylogeny. Response variables and covariates were natural-log transformed, as needed, to ensure model residuals were normally distributed and homoscedastic. In all models, we tested whether the inclusion of phylogenetic correlation in the model error produced significantly better model fit, using a likelihood-ratio test and R^2_σ-difference test between the fully-specified model and a model lacking the phylogenetic effect.

Hypothesis testing The following three hypotheses were tested using PGLMMs fitted using ML estimation:

1. The maximum sustained tensile force is proportional to the cross-sectional area of the endocuticle, and *not* that of the exocuticle.
2. The ultimate tensile strength of the samples is inversely proportional to the ratio of exocuticle to endocuticle at the location of fracture.
3. Young's modulus of the samples is proportional to the length of the snout.

We fitted a fully-specified model with the cross-sectional area of endocuticle and exocuticle at the site of fracture as fixed effects, including an interaction term, and with maximum tensile force sustained prior to fracture as a response variable. This model was then compared to models with only cross-sectional area of either endocuticle or exocuticle as the sole fixed effect in the model. We then tested the first hypothesis by using likelihood-ratio tests and $R^2_{\beta*}$-difference tests between each of the three models.

The hypothesis that

Model selection and fitting

Estimating phylogenetic signal

Code availability

Data availability

REFERENCES

[1] Leslie Lamport, *LaTeX: a document preparation system*, Addison Wesley, Massachusetts, 2nd edition, 1994.