

Figure S1. (A) Schematic drawing of the mandible showing where the measurements were taken (Table S1). TMW = total mandible width, IMW = inner mandible width, ACS = anterior crushing surface width, PCS = posterior crushing surface width. (B) Three-point bending set-up created for the very hard seed size, but it was tested with each seed type. (C) Double guillotine testing device. Physical testing device with tools (blades in this case) mounted on the force transducer (which measures the force during experiments), and on the moveable upper platform. On the right the linear displacement sensor (LDS) measures the distance the upper platform covers during experiments. The box houses the AC induction motor, which rotates the screw in order to move the upper platform.

Force [N]	Displacement [mm]	Force corrected	
0.6462	0.7892	-0.6462	
0.6462	0.92	-0.6462	
0.6462	1.0635	-0.6462	
0.6462	1.1985	-0.6462	
1.9387	1.3504	-1.9387	
0	1.4855	0	-0.1310
-3.2311	1.6121	3.2311	0.2045
-40.0658	1.7218	40.0658	2.3748
-85.9476	1.7809	85.9476	3.7237
-118.9049	1.7851	118.9049	0.4302
-160.9094	1.8189	160.9094	4.7289
-209.3761	1.8569	209.3761	7.0354
-169.3103	1.9581	169.3103	23.2162
0.6462	2.359	-0.6462	101.9443
-1.9387	2.5068	1.9387	143.5270
-2.5849	2.5785	2.5849	
-0.6462	2.5827	0.6462	
-1.2924	2.5827	1.2924	
-0.6462	2.5827	0.6462	

Calculation of the area beneath the curve (= work) according to the equation in the main text.

$$=(0.5*(B6-B5)*(ABS(C6-C5)))+(B6-B5)*C5)$$

-0.1310	Start
101.9443	End
143.5270	Work [N*mm]
0.1435	Work [J]

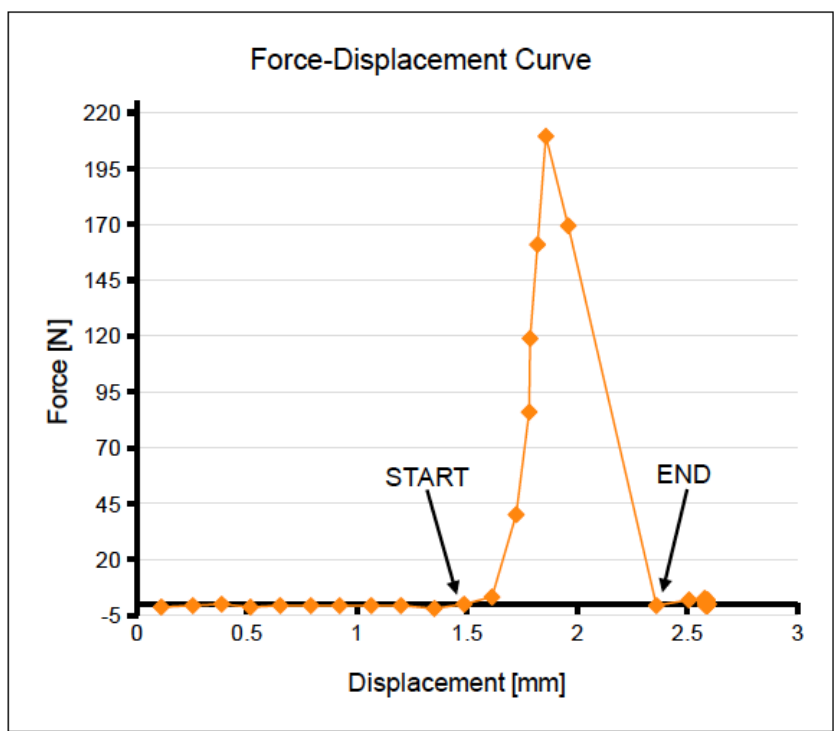


Figure S2. Example for the work value calculation. The diagram shows the area for the integral calculus to get the work value. The area of individual slices between two adjacent data points, the x axis and the curve were calculated, and the work values of the individual slices were added. The start and end points are determined by the last and first data points with $x \approx 0$.

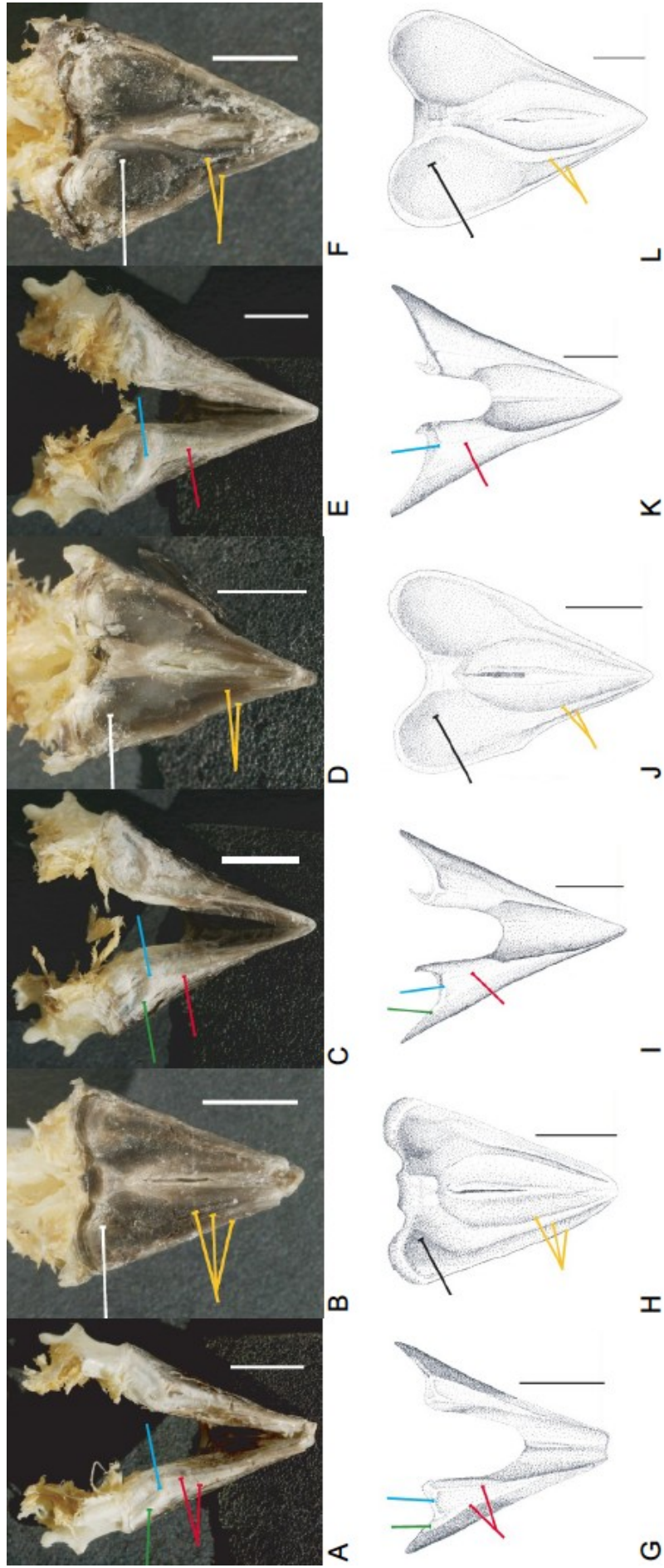


Figure S3. Beak morphology. The upper beaks show more morphological differences than the mandible. The mandibles have grooves and ridges in the anterior part, which are probably used to avoid a shearing or torsion of the two beaks against each other. The posterior part shows slight differences in presence or absence of ridges and the grade of roundness (flat, weak curve, strong curvature). A trend in the mandible is that the side-to-side ridges become longer and better developed the larger the beak. The upper beaks show variations in the dimensions of depressions and ridges. These ridges are further apart the larger the morph. The depressions in the posterior part of the beak are the most variable. In the small morph the depression is narrow and deep. It is shallower, more flattened and wider in the large and the mega morph.

(A, B, G, H) Crushing surface morphology of the small morph. (A, G) Mandible. There is one ridge, which runs on the lingual side from the tip of the beak to the posterior end. After about 5 mm from the tip another ridge originates from the lingual ridge under an angle of less than 20° that runs on the labial side to the posterior end of the mandible. These two anterior-posterior ridges (red arrows) are connected at their posterior ends with another ridge, which runs more or less in the lingual-labial direction, forming a triangle. The width of the side-to-side ridge (blue arrow) is 2-3 mm. The area between these three ridges forms a shallow depression. There are another two short ridges each originating from the posterior edges of the triangle one in the lingual direction and the other one in the labial direction (green arrow). These two ridges probably do not play a role in the cracking process, but may be useful for resisting forces or stabilising the other ridges. All ridges are well developed. The soft seeds fit in the triangle-shaped depression. The crushing surface is flat in the cross section.

(B, H) Upper beak. The upper beak shows a very well developed morphology with clear ridges and depressions. Three ridges (yellow arrows) accompanied by two grooves run from the tip of the beak towards the posterior part. One of the grooves runs towards the middle, enlarges and ends at the medial elevation at the posterior end. The extension of the other groove extends and forms the deep round depression in the posterior part. The ridges and grooves run more or less parallel in the anterior three quarters of the beak. The posterior depressions (white/black arrow) are probably useful to keep the seed in place. A depression with an elevation on the midline forms the centre of the upper beak. All scale bars = 0.5 cm.

(C, D, I, J) Crushing surface morphology of the large morph. (C, I) Mandible. There is one weakly developed ridge which runs from the tip of the mandible in the anterior-posterior direction to the posterior end (red arrow). This ridge is situated at the middle of the crushing surface. The area close to the ridge is flat and nearly horizontal but becomes steeper towards the lingual and labial direction so that the crushing surface looks slightly rounded in the cross section. There is another ridge across the posterior end of the long anterior-posterior ridge with a width of 3-4 mm towards the labial direction (green arrow). After the 3-4 mm it bends under an angle of about 120° towards posterior. The short side-to-side ridge (blue arrow) runs also in the lingual direction, but only for 1-2 mm and bends posteriorly under a sub-perpendicular angle. These short ridges are probably there to resist forces while cracking the seeds rather than being involved in the actual cracking process.

(D, J) Upper beak. Two ridges (yellow arrows) accompanied by one groove run from the tip of the beak towards the posterior part. One ridge forms the outer, labial margin, the other ridge together with the groove extend and enlarge towards the posterior part and form the shallow, rounded and oval depression (white/black arrow). The ridges and the groove run

more or less parallel in the anterior half of the beak. A depression with an elevation on the midline and a high rectangle-shaped elevation at the posterior end forms the centre of the upper beak. There is an edge on each side on the outline of the beak halfway between the anterior and the posterior end; these edges are best to be seen in lateral view. All scale bars = 0.5 cm.

(E, F, K, L) Crushing surface morphology of the mega morph. (E, K) Mandible. The ridge, which runs from the tip of the beak to the posterior edge, is very weakly developed and runs along the middle of the crushing surface (red arrow). From this ridge a very rounded and strongly curved crushing surface originates in the lingual and labial direction in the posterior half of the mandible. The side-to-side ridge (blue arrow) that is situated at the posterior end of the antero-posterior ridge is very well developed and about 4-5 mm wide. This short ridge extends smoothly towards the labial direction and under about 90° towards posterior at the lingual end. The well developed lingual-labial ridge might play a role in the cracking process, but its extensions are probably a support for resisting feeding induced forces.

(F, L) Upper beak. shows a highly flattened morphology; two ridges (yellow arrows) and one groove run from the tip towards the posterior end of the beak. The ridge on the labial side forms the outer margin of the beak, the other one bends towards the midline and continues in the middle posterior elevation. Both ridges are clearly apart from each other and do not run parallel. The groove extends to the wide, rounded and shallow depression (white/black arrow) in the posterior part of the beak. A shallow depression with a broad ridge over the midline and an elevated posterior rectangle is in the centre of the upper beak. All scale bars = 0.5 cm.

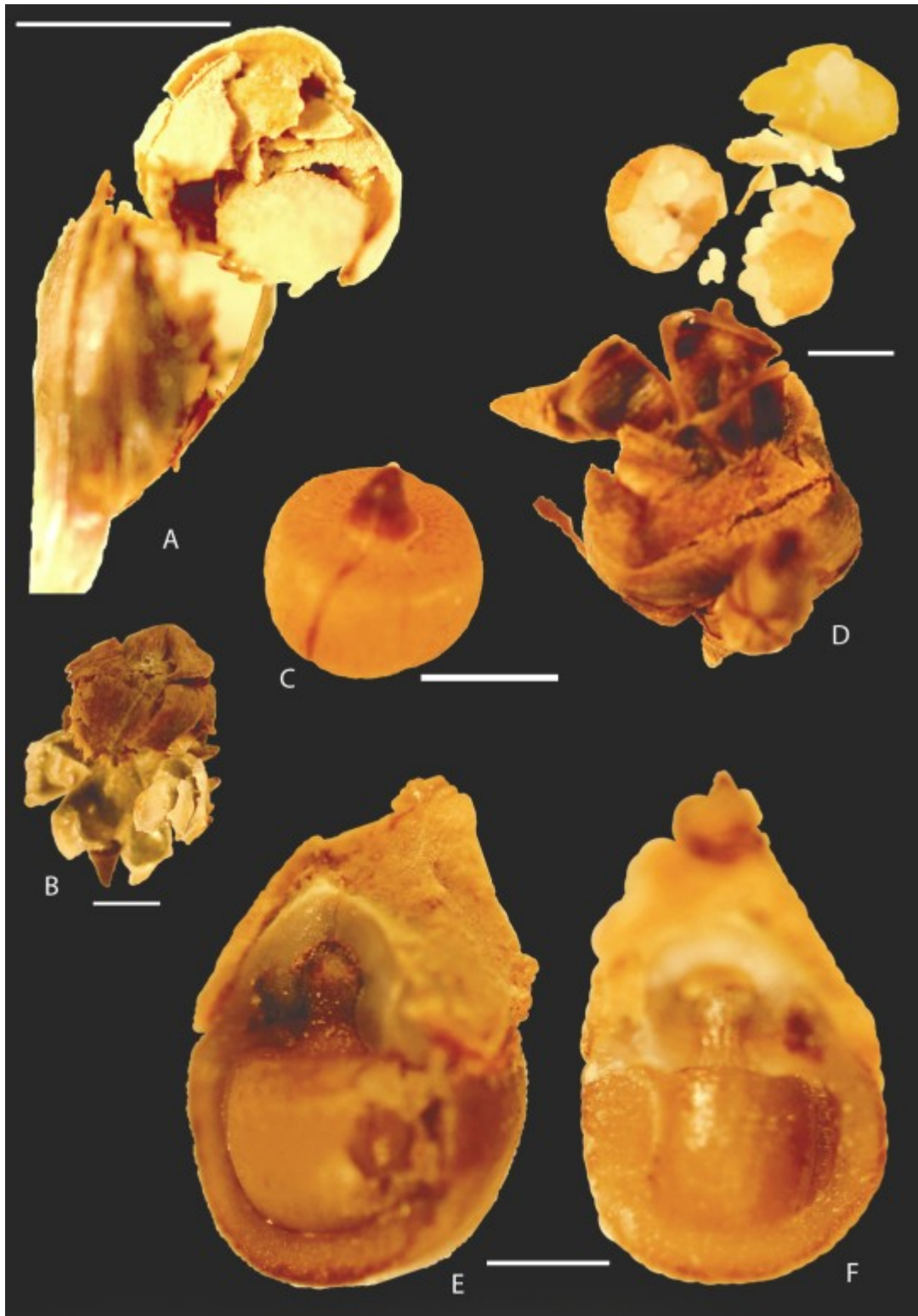


Figure S4. Examples of crushed seeds. (A) A smashed soft seed *Scleria goossensii*. (B) A cracked hard seed *Scleria verrucosa*. (C) A complete fruit of the very hard seed *Scleria racemosa*. (D) A crushed very hard seed resulting from cracking with the 5 mm-tool. (E, F) A very hard seed cracked with the three-point bending tool, cut in two halves and with the whole fruit preserved in the left half. All scale bars = 2 mm.

Table S1. The measurements of the mandibles of the three morphs in mm. Figure S1 shows" where the measurements were taken.

[mm]	small morph	large morph	mega morph
Total mandible width (TMW)	12.33	15.25	17.52
Inner mandible width (IMW)	3.64	2.71	3.10
Anterior crushing surface width (ACS)	2.94	3.51	4.05
Posterior crushing surface width (PCS)	3.32	5.00	6.02

Table S2

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Table S3

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Table S4

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Dataset 1

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