STRESSES IN THE FEEDING PUMP LINING OF DITYLENCHUS DIPSACI
SHOWN BY PHOTOELASTIC ANALYSIS OF PERSPEX MODELS

BY

MALCOLM K. SEYMOUR

Rothamsted Experimental Station, Harpenden, Herts., England

As a step towards understanding the workings of the tylenchid feeding pump, directions of closing stresses (induced in the thickened pump lining when it is opened by the radial muscles) have been determined for *Ditylenchus dipsaci* by an indirect photoelastic method, using Perspex models. The stress pattern is complex and symmetrical; compressive stresses run parallel to the surface on the convex side of the “hinges” as they open, and tensile stresses on the concave side. A point of maximum bending moment lies within each hinge, and points of minimum moment occur midway between the hinges. The cuticle of both hing regions is thought to act as integral springs to close the pump lining. Young’s elastic modulus $E$ was estimated as $3 \times 10^8$ dynes/cm$^2$ and lining material is compared with other resilient animal materials; some tanned ligaments of bivalve molluscs are similar in elastic behaviour and function to the spring hinges of the pump lining. The lining cuticle may also be tanned, and has a fibrous fine structure.

The typical tylenchid feeding pump, the median bulb, is an elongated spheroid through which the oesophageal lumen runs (Fig. 1A). The front and rear ends of the pump consist of subconical masses of non-muscular tissue. Between these are the radial muscles of the pump that attach, by way of the specialised membrane complex (Yuen, 1968) to the cuticularised pump lining (Fig. 1B). The lining can be considered as the surface of a regular solid, the faces of which are formed of three discs sewn together round the circumference so that half of each is attached to half of one of the others. Along the triangular solid run three folds that enable it to close to a triradiate cross-section, and to be opened by the radial muscles to at least a triangular one (Fig. 1B). At its anterior end, the lining may be more round than triradiate in section. Names for parts of the pump lining appear in Fig. 1B; six segments are joined by outer and inner hinge regions.

The mechanism of pumping, and relationship of pumping activity to fine structure of the feeding pump, are being investigated for several nematodes (Seymour & Doncaster, 1977, *in litt.*). The behaviour and properties of the pump lining are of prime importance to feeding on plant cells because the lining is that active pump component which touches ingested food and propels it along the oesophagus.

When the radial muscles open the pump lining, “closing stresses” (that tend to restore it to the closed configuration) are set up in it. As a step towards understanding the workings of a tylenchid feeding pump, directions of closing stresses in the pump lining of *Ditylenchus dipsaci* have been determined by an indirect photoelastic method, using Perspex models.
MATERIALS AND METHODS

Scale models cut from 6-mm Perspex sheet represented median cross-sections of the cuticular pump lining (after Yuen, 1968). Cotton tape muscles applied a naturalistic opening force and models were viewed between crossed Polaroid sheets in a plane polariscope. Birefringence (double refraction) induced in the plastic when it was stressed gave rise to dark isoclinic lines (loci of all points where tension and compression ran parallel to the axes of polarisation of the Polaroids) on a bright image of the model. From these isoclinics, stress-trajectories were visualised by graphic techniques as described by Seymour (1975). The two orthogonally-intersecting networks of stress-trajectories (Fig. 1C) showed directions of the principal stresses set up in the plane of the model by the pull applied to the "muscles".

The photoelastic method is used in industry for design and testing, has been applied to some biological materials (e.g. bones, Kummer 1966; insect mouthparts, Hepburn 1971) and was described by Seymour (1975) as applied to stress-analysis of a nematode stylet.

RESULTS

The pattern of stress-trajectories is practically the same for models representing the closed or opening pump lining. The stress-pattern is complex and symmetrical (Fig. 1C. Compressive stress directions shown by solid, tensile by outline arrows). The outer boundary of the outer hinge region and the inner boundary of the inner hinge region become shorter as the opening force tends to straighten the bends (Fig. 1C, m) so compressive stress-lines appear there. Conversely, straightening creates tensile stresses on the outside of the inner hinge region where the radial muscles attach, as well as round the lumen apices. The inner and outer boundaries of the strained lining section, which are themselves trajectories and where stress normal to them is zero, are divided into alternate regions of tension and compression (Fig. 1C, dotted lines). The transition points between compressed and stretched regions of the boundaries are obviously regions of zero stress. They are isotropic points (points where stress is radial and equal (zero) in all directions in the plane of section) and are called negative because stress trajectories of both compressive and tensile sets loop away from them (Fig. 1C, —). Negative isotropic points indicate regions of minimum bending moment (Kummer, 1966) and so are found midway between inner and outer hinges.

Stress distributions in the inner and outer hinges are rather different from each other, although positive isotropic regions (encircled by stress lines of both sets) appear in both (Fig. 1C, + ). The isotropic region of the inner hinge is a line of zero stress forming a short neutral axis (Fig. 1C). Evidently the parts of the two adjacent pump segments to which the muscles are attached behave like a beam in simple bending. The neutral axis separates an outer part of the lining, in tension, from the inner part in compression. Although the radial stress lines appear continuous across this isotropic line, those inside and outside it belong to different