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Use of X-ray radiography for studying seed quality in tropical forestry

Användning av röntgenradiografi för frökvalitetsbestämning inom tropiskt skogsbruk

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Abstract

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Seeds or fruits of 165 forestry species from nine tropical countries were investigated by x-ray radiography. The results showed that the method can be reliably used for detecting empty, filled, insect-attacked, mechanically damaged and diseased seeds or fruits. The applications of x-ray radiography in tropical forestry for cone, fruit and seed collection, seed processing, nursery practice, seed trade and plant quarantines, and for research etc. are discussed.

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Contents

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1 Introduction

The population of the world is continuously growing and with it also the demand for forest products. In most developing countries wood is used for various basic necessities, such as fuel, house-building, furniture-making, etc. Moreover, the wood-based industries in several developing countries are expanding rapidly and require ever-increasing supplies of raw materials. In addition, forest products are often exported in order to earn foreign currency. All these factors lead to a constantly rising demand for wood and wood products in the world.

The natural forests in many tropical countries are a mixture of various species. The desired trees are often few and far between. Moreover, the dense plant growth and the lack of adequate infra-structure make these forests inaccessible, particularly during the rainy season. Consequently, several tropical countries have started large-scale afforestation and reforestation programmes in order to replace the natural by the man-made forests as far as possible.

Since most afforestation and reforestation programmes start with seed, an adequate supply of good quality seed is of fundamental importance in tree-planting work. Seed supplies are not only affected by flowering and fruiting habits of the species in question, but also by the methods used in collecting, processing and storing seed. Moreover, insects, fungi, bacteria, etc. often attack fruits and seeds during development and storage and thus reduce both their quantity and quality. The situation is worsened by the fact that there is a great lack of knowledge about most of the above-mentioned aspects as well as about structure and physiology of seed in many tropical forestry species. This lack of knowledge together with the shortage of seed supplies of the desired species are two of the most important hindrances in meeting the planting targets in many developing countries. These facts were repeatedly pointed out by the representatives of these countries at the IUFRO International Seed Symposium held in Bergen, Norway, in 1973 (cf. Vols. II and III of the Proceedings). Since the facilities for research are inadequate in most developing countries, their representatives at the Bergen-Symposium urged that seed research for their benefit should be carried out in the developed countries.

The investigation summarized here is another small contribution to the work carried out during the recent years by the author on seed problems of the developing countries (cf. Kamra 1973, 1974 a, and 1975). The purpose of this study was to find out in which ways x-ray radiography can be helpful in determining the quality of tropical forestry seed. The first part of this study has been published earlier by the author (Kamra 1974 b). The second part is presented in this paper.

2 Material and methods

Seeds of 165 species from various tropical countries were used for the investigation. The specifications of the samples are given in Table 1.

The seeds were not pretreated in any way for taking the radiographs. A representative portion of each sample was utilized. It was either spread directly on the envelope containing the film or pasted there with a cellotape. Since the radiographs were to be enlarged and copied on photographic paper for publication, a very slow industrial x-ray film with ultra fine grain ("Structurix D2" from Agfa-Gevaert, Mortsel, Belgium) was used. The exposure conditions were: kV = 14, mA = 5, focus-film distance = 50 cm, exposure time = 1½ to 6 minutes depending upon the thickness of the seeds. The films were processed with the x-ray developer and the x-ray fixative manufactured by CEA Works, Strängnäs, Sweden.

However, for normal observation such a slow film is not needed. Rapid x-ray films are available which require an exposure of only a few seconds for producing good quality radiographs. The processing technique is usually the same both for rapid and slow films.

An illuminated glazed glass plate can be used for observing the radiographic films. Magnification can be obtained with the help of a reading glass. Usually these simple devices allow good viewing. However, special viewers are also available. One such viewer ("Helio Contrastor") was used in the present investigation.

Table 1. Species and countries of the samples investigated.

Sample No.	Name of species	Sample obtained from
1	Aberia caffra Harv. et Sond.	Ethiopia
2	Acacia benthami Meissn.	India
3	Acacia capensis Colla	Chile
4	Acacia catechu Willd.	India
5	Acacia cavenia Mol.	Chile
6	Acacia confusa Merrill	India
7	Acacia decurrens (Wendl.) Willd.	Ethiopia
8	Acacia modesta Wall.	India
9	Acacia mollissima Willd.	Columbia, India
10	Acer oblongum Wall.	India
11	Adenanthera microsperma Teijsm. et Binn.	India
12	Aegle marmelos (L.) Correa	India
13	Aextoxicon punctatum Ruiz et Pav.	Chile
14	Ailanthus excelsa Roxb.	India
15	Albizzia falcataria L. Fosberg	Philippines
16	Albizzia moluccana Miq.	Sri Lanka
17	Alibzzia odoratissima Benth.	India
18	Albizzia procera Benth.	India
19	Albizzia stipulata Boivin.	India
20	Aleurites fordii Hemsl.	India
21	Aleurites moluccana (L.) Willd.	India
22	Aleurites montana (Lour.) E. H. Wils.	India
23	Alnus jorullensis H.B.K.	Colombia
24	Anacardium occidentale L.	Sri Lanka

Sample No.	Name of species	Sample obtained from
25	Anogeissus latifolia Wall.	India
26	Anthocephalus cadamba Miq.	India
27	Araucaria araucana (Molina) K. Koch	Chile
28	Balsamocarpon brevifolium Clos.	Chile
29	Bauhinia purpurea L.	Thailand
30	Bauhinia racemosa L.	India, Sri Lanka
31	Bauhinia retusa Ham.	India
32	Bauhinia variegata L.	India
33	Beilschmedia miersii (Gay) Kosterm.	Chile
34	Bischoffia javanica Blume	India
35	Bombax malabaricum DC.	India
36	Boswellia serrata Roxb.	India
37	Buchanania latifolia Roxb.	India
38	Butea frondosa (Roxb.) Koen.	India
39	Caesalpinia spinosa (Mol.) OK.	Chile
40	Cariniana pyriformis Miers	Colombia
41	Cassia bakeriana Craib.	Thailand
42	Cassia fistula L.	India, Thailand, Sri Lanka
43	Cassia javanica Sieber ex Benth.	India
44	Cassia nodosa Ham.	India
45	Casuarina equisetifolia J. R. et G. Forst.	Thailand
46	Ceiba pentandra (L.) Gaertn.	Sri Lanka
47	Celtis australis L.	India
48	Celtis tetrandra Roxb.	India
49	Chloroxylon swietenia DC.	India
50	Chickrassia tabularis Adr. Juss.	India
51	Chickrassia velutina Roemer	Sri Lanka
52	Cinnamomum camphora Nees	India
53	Cleistanthus collinus Benth.	India
54	Combretum quadrangulare Kurz	Thailand
55	Cordia africana Lam.	Ethiopia
56	Cordia alliodora (Ruiz et Pav.) Cham. et DC.	Colombia
57	Cordia decandra Hook.	Chile
58	Cronodendron patagua Mol.	Chile
59	Croton macrostachys Hochst. ex A. Rich.	Ethiopia
60	Cryptocarya rubra (Mol.) Skeels.	Chile
61	Cupressus arizonica E. L. Greene	Ethiopia
62	Cupressus cashmeriana Royle ex Carrière	India
63	Cupressus torulosa D. Don.	India
64	Dalbergia latifolia Roxb.	India
65	Dalbergia sissoo Roxb. ex DC.	India
66	Dendrocalamus strictus (Roxb.) C. G. Nees	India
67	Derris robusta Benth.	India
68	Dolichandrone falcata Seem.	India
69	Drypetes sepiaria Pax et K. Hoffm.	Sri Lanka
70	Diospyros ebenum Koenig	Sri Lanka
71	Diospyros melanoxylon Roxb.	Sri Lanka
72	Embothrium coccineum Forst.	Chile
73	Entandrophragma caudatum Sprague	Malawi
74	Entandrophragma stolzii Harms	Malawi
75	Erythrina brucei Schweinf.	Ethiopia
76	Eucalyptus globulus Labill.	Ethiopia
77	Evodia roxburghiana Benth.	India
78	Gevuina avellana Mol.	Chile
79	Gliricidia maculata H. B. & K.	India
80	Horsfieldia aculeata Blume	Sri Lanka
81	Ixora parviflora DC.	India
82	Jacaranda filicifolia D. Don	Thailand
83	Jacaranda mimosifolia D. Don	India

Sample No.	Name of species	Sample obtained from
84	Jubaea chilensis (HKB) Johnston	Chile
85	Juniperus chinensis L.	Thailand
86	Juniperus procera Hochst. ex Endl.	Ethiopia
87	Koelreuteria apiculata Rehder et Wilson	India
88	Koelreuteria paniculata Laxm.	India
89	Kydia calycina Roxb.	India
90	Lagerstroemia floribunda Wall.	India
91	Lagerstroemia speciosa (Murr.) Pers.	Thailand
92	Lagerstroemia tomentosa Presl.	Thailand
93	Laucilia glauca L.	Thailand
94	Laurelia sempervirens Tul.	Chile
95	Laurelia serrata Ph.	Chile
96	Leucaena glauca Benth.	Chile
97	Lithraea caustica (Mol.) H. et A.	Chile
98	Lomatia hirsuta (Lam.) Diels	Chile
99	Lonchocarpus capassa Rolfe	Malawi
100	Madhuca longifolia Macbride	Sri Lanka
101	Markhamia stipulata Seem.	Thailand
102	Maytenus boaria Mol.	Chile
103	Melia composita Willd.	India
104	Melia dubia Car.	Sri Lanka
105	Mesua ferrea L.	India
106	Michelia champaca L.	India
107	Mitragyna parvifolia Korth.	India
108	Nothofagus alpina (Poepp. et Endl.) Oerst.	Chile
109	Nothofagus dombeyi (Mirb.) Blume	Chile
110	Nothofagus obliqua (Mirb.) Oerst.	Chile
111	Nothofagus pumilio (Poepp. et Endl.) Drass.	Chile
112	Olea africana Mill.	Ethiopia
113	Ostryoderris stuhlmanii Dunn ex Bak	Malawi
114	Ougeinia dalbergioides Benth.	India
115	Parashorea plicata Brandis	Philippines
116	Peltophorum africanum Sond.	India
117	Peltophorum dasyrachis Kurz	Thailand
118	Peltophorum dubium Taub.	India
119	Pentacme mindanensis Foxw.	Philippines
120	Persea lingue Nees	Chile
121	Peumus boldus Mol.	Chile
122	Pinus caribaea Morelet	Tanzania
123	Pinus kesiya Royle & Gordon	Thailand
124	Pinus merkusii Jungh & De Vriese	Thailand
125	Pinus oocarpa Schilde	Colombia
126	Podocarpus andinus Poepp.	Chile
127	Podocarpus gracilior Pilger	Ethiopia
128	Podocarpus neriifolia Don	India
129	Pongamia glabra Vent.	India
130	Prosopis chilensis (Mol.) Stuntz	Chile
131	Prosopis tamarugo Phil.	Chile
132	Pseudosamanea guachapele Harms.	Colombia
133	Pterocarpus angolensis DC.	Malawi
134	Pterocarpus indicus Willd.	Philippines
135	Pterocarpus vidalianus Rolfe.	Philippines
136	Pterospermum acerifolium Willd.	India
137	Putranjiva roxburghii Wall.	India
138	Quillaja saponaria Mol.	Chile
139	Roystonea regia Cook	Thailand
140	Sapindus detergens Roxb.	India
141	Schleichera oleosa (Lour.) Oken.	Sri Lanka
142	Schinus molle L.	Chile, Ethiopia

Sample No.	Name of species	Sample obtained from
143	Schinus polygamus (Cav.) Cabr.	Chile
144	Semecarpus anacardium L. f	India
145	Shorea almon Foxworthy	Philippines
146	Shorea guiso (Blanco) Bl.	Philippines
147	Shorea polysperma (Blanco) Merrill	Philippines
148	Shorea squamata Dyer	Philippines
149	Sophora macrocarpa Smith	Chile
150	Sophora tetraptera Ait.	Chile
151	Stenolobium stans Seem.	Thailand
152	Streblus asper Lour.	Thailand
153	Strychnos nux-vomica L.	India
154	Swietenia macrophylla King	Philippines, Sri Lanka
155	Tamarindus indica L.	India
156	Taxodium mucronatum Ten.	India
157	Terminalia arjuna Bedd.	Sri Lanka
158	Terminalia belerica Roxb.	India
159	Terminalia chebula Retz.	India
160	Terminalia sericea Burch	Malawi
161	Terminalia tomentosa W. & A.	India
162	Trewia nudiflora L.	India
163	Vitex parviflora Juss.	Philippines
164	Widdringtonia whytei Rendle	Malawi
165	Wrightia tinctoria R. Br.	India

3 Results

In principle, a radiograph should be published in the same form in which it appears on the x-ray film ("negative form") (cf. Yates 1975). This technique requires the use of an intermediate film to copy the radiograph. Unfortunately, in the present radiographs the above procedure led to considerable loss of detail. Therefore, the x-ray pictures reproduced photographically in the enclosed figures have been printed without using an intermediate film ("positive form"). The following observations can be made from them.

3.1 Empty and filled seeds

By x-ray radiography it is easy to differentiate empty, incompletely-developed and fully-developed seeds in a sample. Also the degree of development of the various parts of a seed, e.g. embryo, endosperm, cotyledons, etc. can be readily observed from the radiographs. Examples of well-developed (a), shrivelled or incompletely-developed (b) and/or empty (c) seeds are given in Figures: 11, 15, 22, 39, 73, 82, 96, 135, 162, etc.

3.2 Insect-damage

Seeds and fruits are damaged in various ways by insects. A common way is that insects lay their eggs in the fruits or seeds and the developing larvae devour the contents and then come out. In some cases insect excrements are found in the seeds or the fruits. Certain insects insert their stylets through the cones into the developing seeds and by secreting enzymes suck in the contents. This type of insect damage often leads to the formation of empty seeds (cf. De Barr 1970, De Barr and Ebel 1973). The following figures show examples of insect damage to seeds or fruits: 4 e_1—e_2, 5 e_1—e_4, 8 e_1—e_3, 10 e, 16 e_1—e_2, 18 e_1—e_2, 25 e, 29 e_1—e_3, 32 e_1—e_2, 58 e_1—e_2, 66 e_1—e_3, 71 e_1—e_2, 89 e_1—e_2, 100 e, 109 e_1—e_2, 114 e_1—e_2, 155 e_1—e_2, etc.

3.3 Mechanical damage

Fruits and seeds can get mechanically damaged during handling. Such damage usually manifests itself as cracks, fissures, etc. Some examples are given in Figures: 1 d, 4 d, 8 d, 15 d, 17 d_1—d_2, 52 d, 70 d, 98 d, 99 d, 111 d, 125 d, 138 d, 154 d, etc.

3.4 Diseases

In the case of diseased seeds or fruits, it is the discoloured tissue which is usually visible on the radiographs. This tissue seems to possess a lesser capacity to absorb x-rays than the healthy tissue and consequently appears darker on the x-ray film. Fruits and seeds which appeared to be diseased on the radiograph were dissected and their diseased condition could be confirmed. Examples are to be found in Figures: 6 f, 31 f_1—f_2, 64 f, 74 f, 113 f_1—f_2, 130 f.

3.5 Contents of a fruit

The contents of a fruit can be observed without opening it with the help of x-ray radiography. In this way, the number of seeds in a fruit can be easily determined. Thus, empty fruits can be distinguished from those containing seed. Examples are Figures: 55 a, c + a; 57 a & c; 129 a & e;

133 a & c; 135 a & c; 157 a & e, 163 c + a and $c_1 + a_1$, etc.

3.6 Other variations

Internal fissures are visible in Figures 7 g and 149 g. A seed of *Araucaria araucana* showing a curved embryo is seen in Fig. 27 g. Figure 112 g shows a two-seeded fruit of *Olea africana*. Usually the fruit of *Olea* is one-seeded (cf. Troup 1921 and U.S.F.S. 1974). Another example of a two-seeded fruit is found in Figure 126 g. Two fruits grown together, a well-developed and a poorly-developed, are seen in Figure 139 g.

4 Discussion

The results described above indicate several uses of x-ray radiography in tropical forestry. Here are a few examples.

4.1 Cone, fruit or seed collection

In many tropical forestry species, the suitable time for collecting cones, fruits or seeds is an important practical problem (e.g. in *Pinus patula,* cf. Shehaghilo 1973). For this purpose, x-ray radiography can be used to study seed development in a few samples gathered from the area in question. When the seed has reached the required stage of maturity, the cones, fruits or seeds are ready for collection.

Also for making a forecast of the expected seed quality in a particular species and area, x-ray radiography can be utilized. Thus, collection can be made only in those stands where seed is of the desired quality (cf. also Wang 1971). In this way, labour and expense can be saved.

4.2 Mechanical damage

The mechanical damage to seed can usually be observed on the radiograph without giving any special treatment to seed (cf. Results, and also Belcher 1974 b). However, if the damage cannot be seen in this way, a treatment with a suitable contrast agent can be undertaken. Some liquid and vaporous contrast agents have been used to detect mechanical damage to *Pinus silvestris* seed (cf. Kamra 1963, Simak 1974 a & b). It is possible that this technique, eventually with some modification, can be applied to tropical seed as well.

4.3 Seed processing

Seed often suffers mechanical damage during processing. Thus, by checking the mechanical damage to seed radiographically before and after a particular step in processing, the source of the damage can be discovered. Through removal or improvement of the source concerned, the mechanical damage to seed can be reduced, thus improving seed quality.

Radiography can also be used in another way to improve the quality of seed during processing. Since empty, poorly-developed, insect-attacked seeds, etc. can be detected by this technique, steps can be taken during processing to remove such seeds from the sample (e.g. through grading or flotation etc.). The quality of the seed lot can be checked radiographically before and after such a treatment.

4.4 Seed storage

As a rule, only such seed should be stored which will retain its viability satisfactorily during storage. It has been shown earlier that mechanically damaged seed loses its viability more rapidly during storage than undamaged seed (cf. Kamra 1967). Since mechanical damage to a sample can be detected radiographically, necessary steps can be taken; e.g. the seed lot can be sown as soon as possible. In this way, by shortening the period of storage, the loss of seed viability can be reduced.

4.5 Cause for non-germination of seeds

In most germination tests, some seeds remain ungerminated at the end of the test.

There are different causes for their inability to germinate. These seeds may be empty, incompletely-developed, insect-attacked, diseased, or only dormant, etc. Usually, such seeds are dissected to find the cause. This procedure is not only time-consuming, but also sacrifices the seeds so that the germination test cannot be continued where necessary. X-ray radiography can disclose the cause for the non-germination of seeds without harming them.

4.6 Nursery practice

For obtaining satisfactory plants in the nursery, it is important to sow seed of high quality. Through the use of x-ray radiography, empty, poorly-developed, insect-attacked, diseased seeds, etc. can be detected in the sowing material. The seed rate can then be adjusted accordingly to obtain the required number of seedlings. In this way, space, labour and cost for the production of seedlings in the nursery can be reduced.

4.7 Seed trade and plant quarantines

The detection of insects and diseases in tropical forestry seed moving in international trade is an important problem. Here again x-ray radiography is valuable, particularly for revealing insects in seed (also cf. Havel 1974). In this way, not only the quality of the seed being bought or sold can be checked rapidly, but also the spread of insects and diseases to new areas or countries can be reduced.

4.8 Uses in research

X-ray radiography has several applications in genetical, entomological, embryological and other research in tropical forestry. Here are a few examples.

(a) *Genetical*: Seed produced by controlled crossing in genetical experiments is usually available in limited quantities. In this case it is particularly important to know whether the seed is capable of producing any seedlings or not. This can be done by studying the development of embryo, endosperm, etc. in fresh seed. For this purpose, x-ray radiography is almost the only method which enables the geneticist to get this information about his material without cutting and thus destroying it (cf. also Cox 1973). Moreover, any structural abnormalities in the seed can also be easily detected by this method. The x-ray technique not only saves time and labour, but above all keeps the valuable material undamaged. Thus further studies can be undertaken on the same material which has been investigated radiographically.

(b) *Entomological*: Insects are an important problem in several tropical species (e.g. *Pagida salvaris* and *Hyblaea puera* in *Tectona grandis L.,* Kittinanda 1973; *Apion* sp. in *Triplochiton scleroxylon* K. Schum., Jones and Kudler 1971 a; *Nanophyes* sp. and *Auletobius* sp. in *Terminalia ivorensis* A. Chev., Jones and Kudler 1971 b; etc.). In some cases they cause damage to the developing fruits or seeds, in others, during their storage. Commonly, the fruits or seeds are dissected to detect the insects in them. This time-consuming procedure can be replaced by x-ray radiography. Moreover, the radiographic method has certain other advantages as well, which are pointed out by Yates (1974) as follows:

"More importantly, this non-destructive technique permits certain studies that could not be conducted otherwise. It is particularly important in the study of insect development within seeds. Without radiography, detailed study would require dissecting the seed, thereby destroying the microenvironment and altering the insect's behaviour and development. This dissection sacrifices both the insect and the seed and does not permit continuous undisturbed observation of individuals from egg laying to emergence."

For further examples of the use of x-ray radiography in research, see Kamra (1974 c).

4.9 "Can x-ray radiography be utilized by the tropical countries?"

This question is often asked. Therefore it is necessary to discuss it here. From what has been described above, it is clear that x-ray radiography has many applications in tropical forestry. Despite this, its use in tropical countries has been limited so far. Several factors are responsible for this. Probably the most important one is the fact that the majority of the tropical countries are developing countries with insufficient resources of finance, equipment and trained personnel. This reduces their possibilities to undertake research. Most of the work on x-ray radiography has been carried out in the developed countries and has naturally been concentrated on their own species (largely temperate). This together with the fact that there is not adequate exchange of information between the developed and the developing countries (cf. Vols. II and III of the IUFRO Seed Symposium, Bergen, 1973), has led to the belief that x-ray radiography is an expensive method requiring highly trained personnel and can thus be used in rich and advanced countries only. In view of this, the potentialities of x-ray radiography in tropical forestry have not been realized.

Contrary to the above belief, the x-ray equipment for seed radiography today is neither particularly expensive nor does it require highly trained personnel. Low price x-ray units are available. They repay their cost not only by reducing the time and labour, but also by increasing the reliability of the results. About seed radiography and the question of trained personnel for this work, Yates (1974) states: "There are a number of advantages to radiography. The technique is fast, simple, can be standardized, and is suited to the handling of large quantities of many sizes and shapes of seed. Usually, interpretation of the radiograph is simple and can be done by a nontechnical employee with a minimum amount of instruction."

The technical developments in designing x-ray equipment, particularly during the recent years, have resulted in models which are specially suitable for seed radiography. They are usually small in size, light in weight and can be easily placed in a seed laboratory. Unlike the equipment used in medical and industrial radiography which is intended to generate high-energy ("hard") x-rays with high penetration power, the seed units are meant to produce low-energy ("soft") x-rays with low penetration power. Consequently, the safety measures needed are much simpler. Most of the modern seed radiography units have bulit-in safety devices which protect the operator from incidental exposure.

Also through improvements in the image recording materials and processing equipment, x-ray radiography of seed has become a simplified procedure. Films wrapped in light-tight envelopes enable exposure in the presence of light. Also film processing equipment has been improved over the years. Today it is neither expensive nor difficult to process x-ray films. Wherever a large number of films has to be processed every day (e.g. in hospitals), film processors can be utilized. Although rather expensive at the moment, these machines justify their use not only by shortening the processing time but also by reducing the labour and costs involved in dark-room work.

The use of the polaroid system in seed radiography does away with the need for a dark room. Both exposure and processing can be carried out in the presence of light. Moreover, two radiographs (a negative on film and a positive on paper) can be obtained from the same exposure. Edwards (1973) describes this technique for seed work.

The instant x-ray paper by Kodak ("Industrex 600") is still a step further in making seed radiography simpler and quicker to work with. The paper can be processed in 10 seconds in an instant processor and can then be examined immediately. Belcher (1974 a) explains this technique and points out its advantages for seed analysis. Some of the recent developments in x-ray radiography for seed testing and research have been reviewed by the author in a separate paper (Kamra 1974 c).

All these improvements in the equipment and the materials have made x-ray radiography simpler and more useful for seed work. Therefore, it can be easily employed in forestry in the tropical countries as well. Thus, Belcher (1974 c) predicts an increased use of the method in seed testing and research in the coming years.

5 Conclusion

To conclude, it can be said that x-ray radiography rapidly and clearly distinguishes good seed from that with different kinds of defects. Therefore, the technique has many applications in seed work as well as in other areas of tropical forestry, e.g. Genetics, Entomology, Pathology, etc. Moreover, the recent improvements in the radiographic equipment and materials have made this method simpler and easier to work with. It is hoped that an increased understanding of the potentialities of this technique in tropical forestry will widen its use there. In this way, x-ray radiography can contribute to the improvement of tropical forestry and this in its turn to the advancement of the developing countries.

6 Zusammenfassung

Samen oder Früchte von 165 forstlichen Arten aus neun tropischen Ländern wurden röntgenologisch untersucht. Die Ergebnisse zeigten, dass mit dieser Methode die Unterscheidung von leeren, vollen, insektbefallenen, mechanisch-beschädigten und mit Krankheiten behafteten Samen oder Früchten in zuverlässiger Weise durchgeführt werden kann. Die Anwendungsmöglichkeiten der Röntgenradiographie in der tropischen Forstwirtschaft für die Sammlung von Zapfen, Früchten und Samen, die Samenbehandlung, die Baumschul-arbeiten, der Samenhandel und die Pflanzenquarantäne sowie die Forschung usw. sind diskutiert worden.

7 Sammanfattning

Frö eller frukter av 165 skogliga arter från nio tropiska länder undersöktes med röntgenradiografi. Namnen på arterna samt länderna från vilka proven erhållits är angivna i tabell 1. Resultaten visade att metoden på ett tillförlitligt sätt kan användas för att upptäcka tomma, matade, mekaniskt skadade och insekts- och sjukdomsangripna frön eller frukter. Användningsmöjligheterna för röntgenradiografi inom tropiskt skogsbruk för insamling av kottar, frukter och frö, fröbehandling, plantskolearbeten, fröhandel, plantkarantän och skogsforskning har diskuterats.

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Legend to Figures

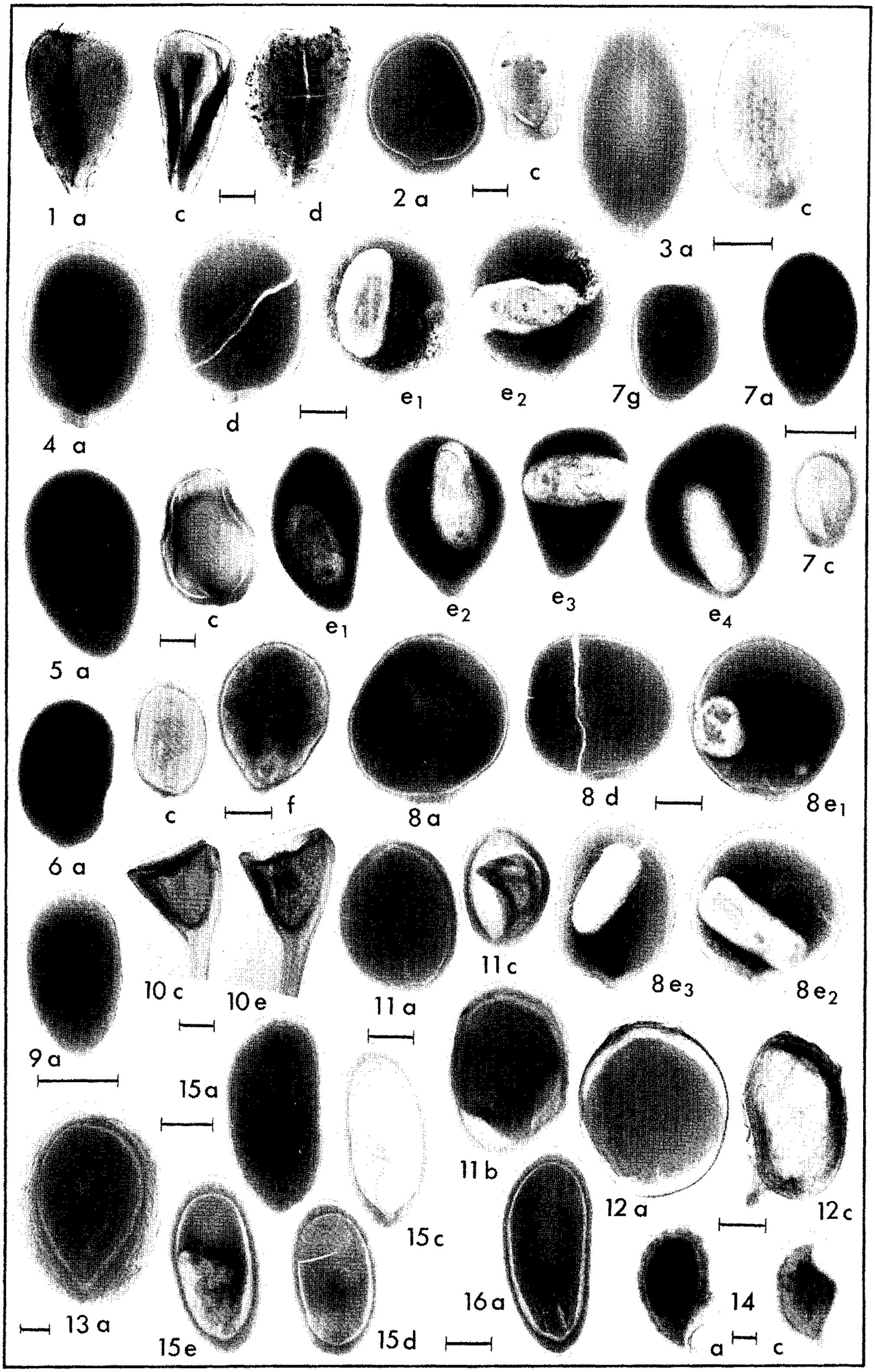
Radiographs showing seed or fruit:

a = Well-developed
b = Shrivelled or poorly-developed
c = Empty
d = Mechanically damaged
e = Insect attacked
f = Diseased
g = With other variations

1. Aberia caffra.
2. Acacia benthami.
3. Acacia capensis.
4. Acacia catechu. e_1—e_2: Different degrees of insect attack.
5. Acacia cavenia. e_1—e_3: Various stages of insect development in the seeds. Note that the insect structures can be clearly studied from the radiographs e_2—e_3. e_4: The insect has moved out of the seed.
6. Acacia confusa. f: A diseased seed.
7. Acacia decurrens.
8. Acacia modesta. e_1—e_3: Different degrees of insect development in the seeds.
9. Acacia mollissima.
10. Acer oblongum.
11. Adenanthera microsperma. c: Observe embryonal rests in the empty seed.
12. Aegle marmelos.
13. Aextoxicon punctatum.
14. Ailanthus excelsa.
15. Albizzia falcataria. c: Empty seed. d. Seed showing a transverse crack. e: Seed with insect damage.
16. Albizzia moluccana.
17. Albizzia odoratissima. d_1—d_2: Seeds showing 1 and 2 cracks respectively. e_1—e_2: Developing insects in the seeds.
18. Albizzia procera. e_1: The insect anatomy is distinctly visible inside the seed.
19. Albizzia stipulata.
20. Aleurites fordii. e: Note emptiness caused by insect attack.
21. Aleurites moluccana. e: The hole bored by insect is seen on the upper left side.
22. Aleurites montana. b: A seed with shrunken contents. c: The contents have been completely eaten up by insects.
23. Alnus jorullensis.
24. Acacardium occidentale.
25. Anogeissus latifolia.
26. Anthocephalus cadamba. a_1—a_2: Fruits containing different numbers of seeds.
27. Araucaria araucana. g: Note the curved embryo.
28. Balsamocarpon brevifolium. c: Empty seed. e: Empty seed due to insect attack.
29. Bauhinia purpurea. e_1—e_3: Different degrees of insect damage to seeds.
30. Bauhinia racemosa.
31. Bauhinia retusa. f_1—f_2: Observe diseased areas in the seeds.
32. Bauhinia variegata.
33. Beilschmedia miersii.
34. Bischoffia javanica.
35. Bombax malabaricum.
36. Boswellia serrata.
37. Buchanania latifolia. d: Crack in the seed.
38. Butea frondosa.
39. Caesalpinia spinosa. b: Incompletely developed seed.
40. Cariniana pyriformis.
41. Cassia bakeriana.
42. Cassia fistula. e_1—e_2: Note insect development in the seeds.
43. Cassia javanica.
44. Cassia nodosa.
45. Casuarina equisetifolia. e: Developing insect in the middle of the seed.
46. Ceiba pentandra.
47. Celtis australis. c: Empty fruit.
48. Celtis tetrandra.
49. Chloroxylon swietenia. b: Incompletely developed seed.
50. Chickrassia tabularis.
51. Chickrassia velutina.
52. Cinnamomum camphora. d: Many cracks in the seed.
53. Cleistanthus collinus.
54. Combretum quadrangulare.
55. Cordia africana. c + a: Fruit showing one developed and one empty seed. c: Fruit showing two empty seeds. e_1—e_2: Developing insects in the fruits.
56. Cordia alliodora. a: One seeded fruit.
57. Cordia decandra. a: Fruit showing four well-developed seeds. c: Fruit showing four empty seeds.
58. Cronodendron patagua. e_1—e_2: Observe the insect development in the seeds.
59. Croton macrostachys.
60. Cryptocarya rubra.
61. Cupressus arizonica.
62. Cupressus cashmeriana.
63. Cupressus torulosa.

64. Dalbergia latifolia. f: Note the diseased tissue in the top right-hand corner.
65. Dalbergia sissoo.
66. Dendrocalamus strictus. c + a: An empty and a well-developed seed. e_1—e_3: Various degrees of insect attack. Observe the hole bored by insect on top of the seed in e_3.
67. Derris robusta.
68. Dolichandrone falcata.
69. Drypetes sepiaria.
70. Diospyros ebenum. d: Cracks in the empty seed.
71. Diospyros melanoxylon. e_1—e_2: Partially and fully insect damaged seeds.
72. Embothrium coccineum.
73. Entandrophragma caudatum.
74. Entandrophragma stolzii. f: Note the diseased tissue on top right of the seed.
75. Erythrina brucei. d: Seed showing longitudinal cracks.
76. Eucalyptus globulus.
77. Evodia roxburghiana.
78. Gevuina avellana. d: Many transverse cracks visible in the seed.
79. Gliricidia maculata. e: Insect damaged seed.
80. Horsfieldia aculeata.
81. Ixora parviflora.
82. Jacaranda filicifolia.
83. Jacaranda mimosifolia. c: Empty seed.
84. Jubaea chilensis.
85. Juniperus chinensis. a: Seed with a well-developed embryo.
86. Juniperus procera.
87. Koelreuteria apiculata.
88. Koelreuteria paniculata.
89. Kydia calycina. e_1: Developing insect visible in the seed. e_2: Insect has left the seed.
90. Lagerstroemia floribunda.
91. Lagerstroemia speciosa.
92. Lagerstroemia tomemtosa.
93. Laucilia glauca. e_1—e_2: Seeds showing insect attack.
94. Laurelia sempervirens.
95. Laurelia serrata.
96. Leucaena glauca. c_1—c_2: Empty seeds of different forms.
97. Lithraea caustica. e_1: A developing insect in the fruit. e_2: The insect has left the fruit. The tunnel bored by it is visible.
98. Lomatia hirsuta. d: Seed showing several cracks.
99. Lonchocarpus capassa. d: Note the broken radicle (top right).
100. Madhuca longifolia. e: Insect remains are visible.
101. Markhamia stipulata.
102. Maytenus boaria. d: A longitudinal crack is observable.
103. Melia composita.
104. Melia dubia.
105. Mesua ferrea.
106. Michelia champaca. e: Seed filled with insect remains.
107. Mitragyna parvifolia. a: Fruit head. a_1: Seed.
108. Nothofagus alpina.
109. Nothofagus dombeyi. e_1—e_2: Note the developing insects in the seeds.
110. Nothofagus obliqua.
111. Nothofagus pumilio. d: A large transverse crack is visible in the seed.
112. Olea africana. a: One-seeded fruit. g: Two-seeded fruit.
113. Ostryoderris stuhlmanii. f_1: Seed showing diseased area on top left. f_2 Most of the seed diseased.
114. Ougeinia dalbergioides. e_1—e_2: Partially and almost completely insect damaged seeds in the fruits.
115. Parashorea plicata.
116. Peltophorum africanum. e: Note the insect damage.
117. Peltophorum dasyrachis.
118. Peltophorum dubium.
119. Pentacme mindanensis.
120. Persea lingue.
121. Peumus boldus.
122. Pinus caribaea. c: An empty seed showing a crack. d: A well-developed seed with a crack.
123. Pinus kesiya.
124. Pinus merkusii.
125. Pinus oocarpa. d: Note cracks in the seed.
126. Podocarpus andinus. a: A one-seeded fruit. g: A two-seeded fruit.
127. Podocarpus gracilior.
128. Podocarpus neriifolia. b: Fruit with incompletely developed seed. c: Empty fruit.
129. Pongamia glabra.
130. Prosopis chilensis. a: A well-developed healthy seed. f: A diseased seed. Note diseased areas on the lower left and on the right side of the seed.
131. Prosopis tamarugo.
132. Pseudosamanea guachapele. e_1—e_2: Observe the developing insects in the seeds.
133. Pterocarpus angolensis.
134. Pterocarpus indicus. a + c: Two chambers with well-developed seeds and two empty.
135. Pterocarpus vidalianus.
136. Pterospermum acerifolium.
137. Putranjiva roxburghii.
138. Quillaja saponaria. d: Note a deep crack in the middle of the seed.
139. Roystonea regia. g: Two fruits, a well-developed and a poorly-developed, grown together.
140. Sapindus detergens.
141. Schleichera oleosa.
142. Schinus molle. a: Configurations on the seed coat are visible.
143. Schinus polygamus.

144. Semecarpus anacardium.
145. Shorea almon. a: A well-developed fruit. e: An insect-damaged fruit.
146. Shorea guiso.
147. Shorea polysperma.
148. Shorea squamata.
149. Sophora macrocarpa. g: Note transverse internal fissures in the seed.
150. Sophora tetraptera.
151. Stenolobium stans. e_1—e_2: Different degrees of insect damage.
152. Streblus asper.
153. Strychnos nux-vomica.
154. Swietenia macrophylla. d: Observe transverse cracks.
155. Tamarindus indica. e_1—e_2: Note the insect damage.
156. Taxodium mucronatum.
157. Terminalia arjuna. e: The holes caused by insects are visible.
158. Terminalia belerica.
159. Terminalia chebula.
160. Terminalia sericea. e: Insect damage on top right.
161. Terminalia tomentosa.
162. Trewia nudiflora.
163. Vitex parviflora. $c + a$ and $c_1 + a_1$: Fruits containing empty and well-developed seeds.
164. Widdringtonia whytei.
165. Wrightia tinctoria.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e4
7 c
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f
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8 d
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9 a
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10 e
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a
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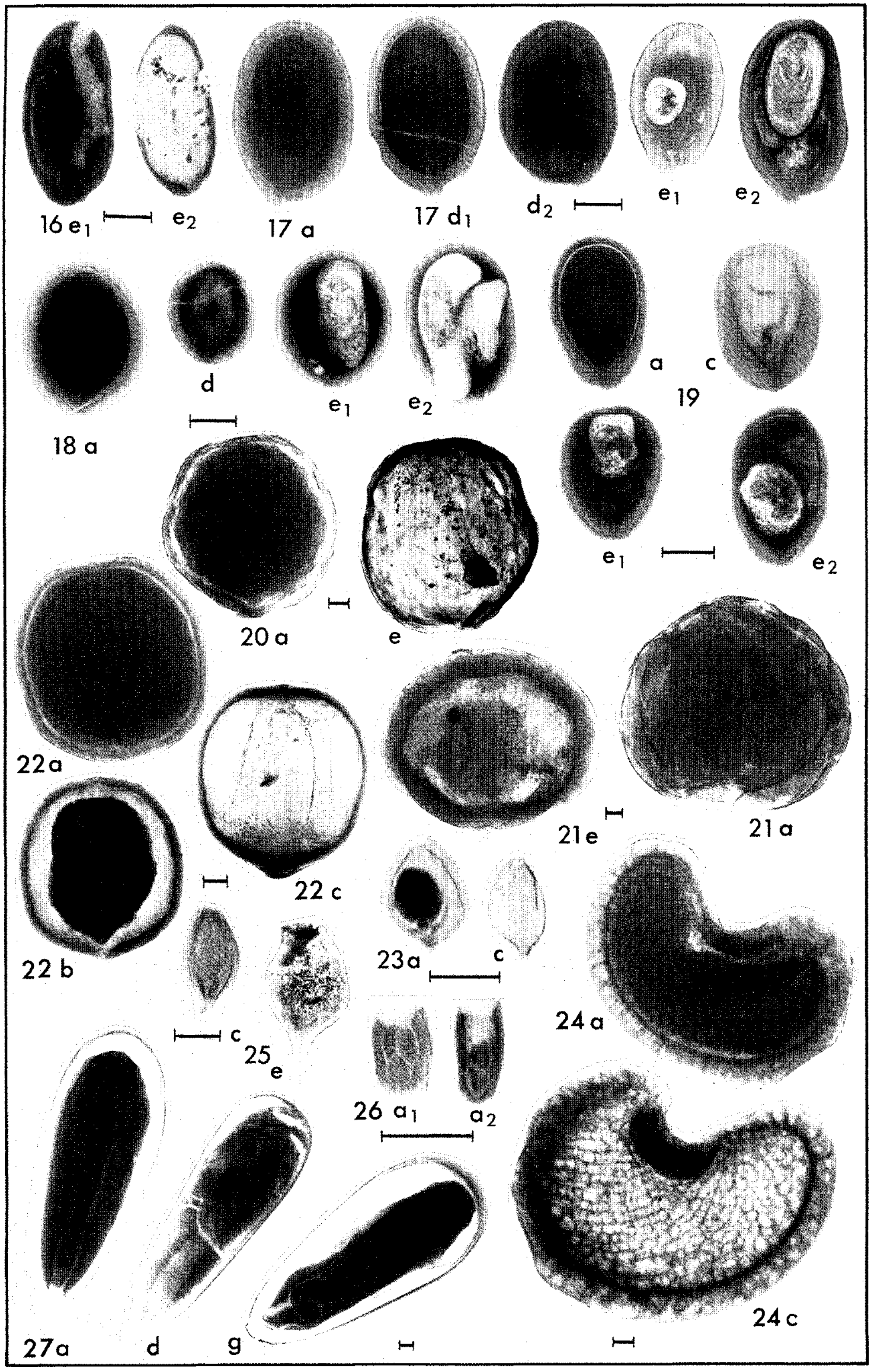

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e_1
e_2
20 a
e
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25 e
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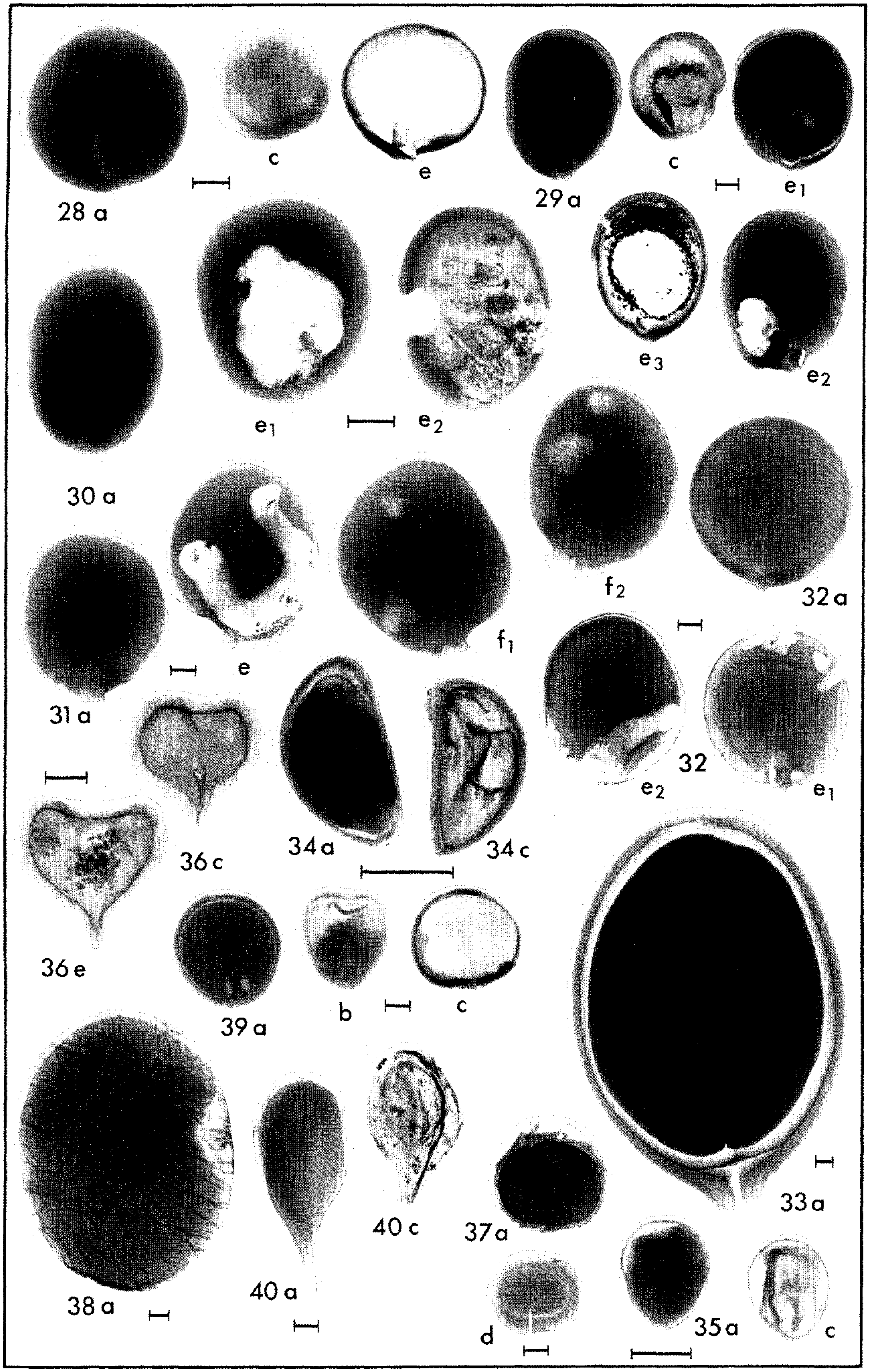
a_2
27 a
d
g
24 c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e_2
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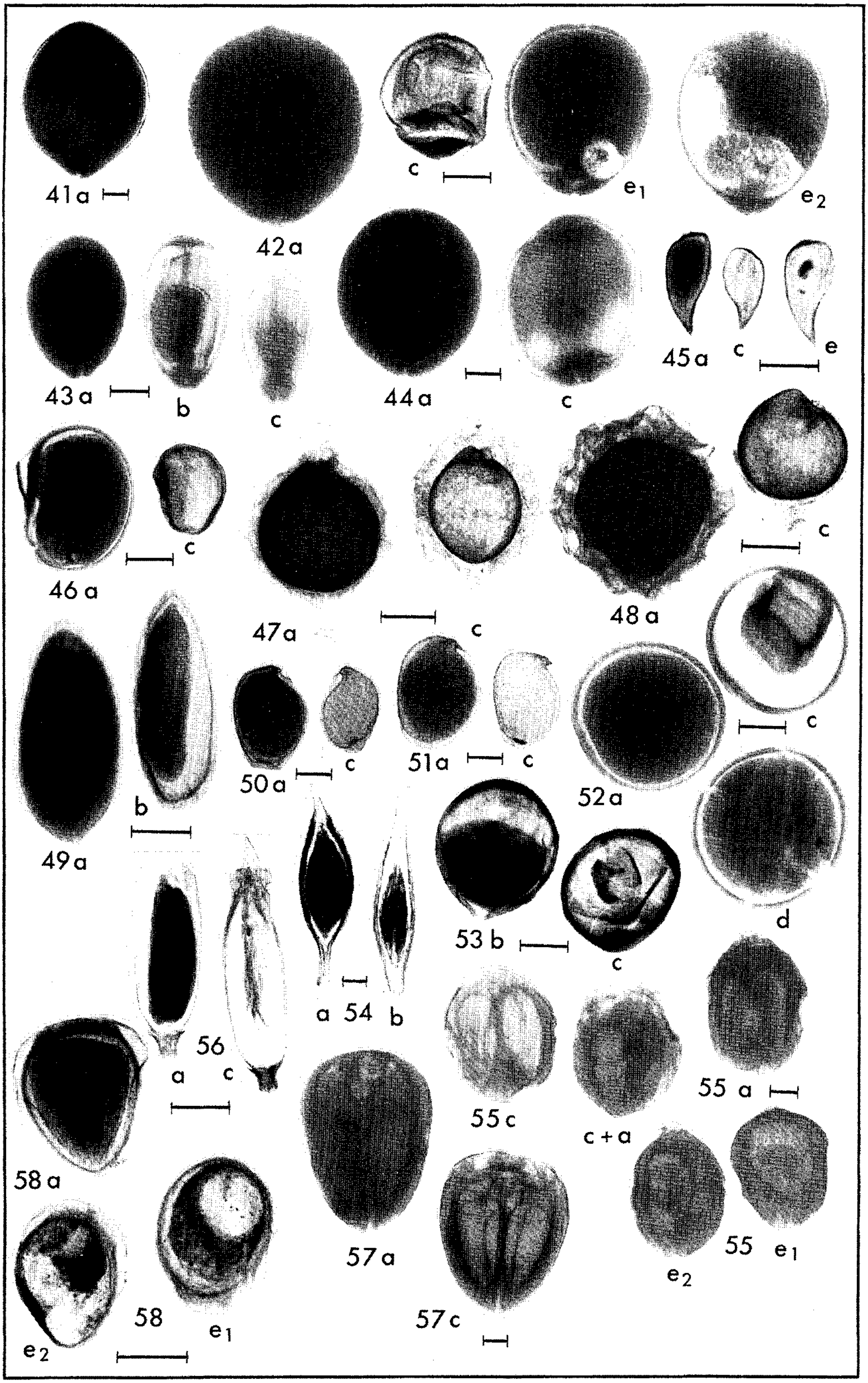

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c
49 a
b
50 a
c
51 a
c
52 a
c
d
53 b
c
a 54 b
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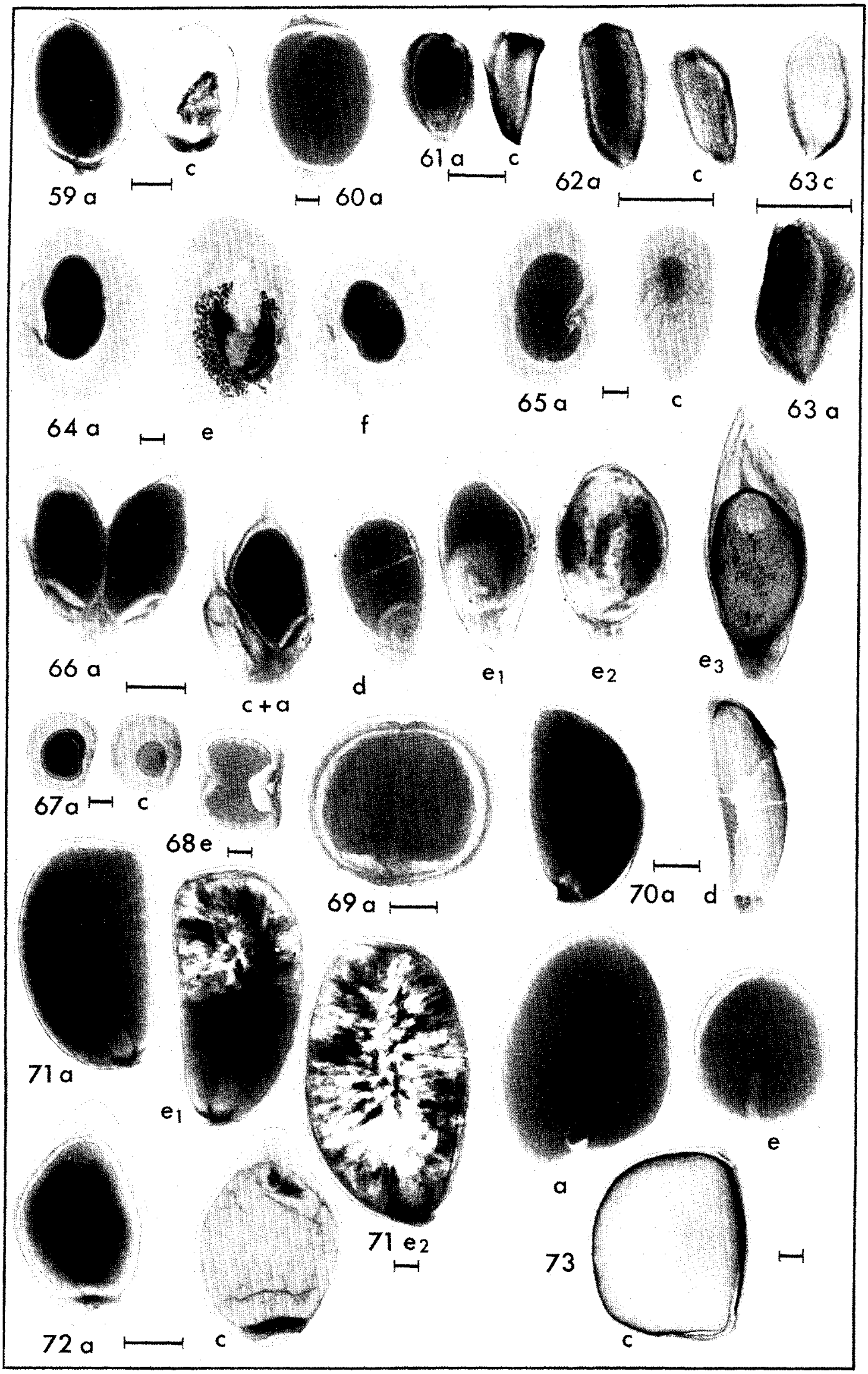
e2
55
e1
e2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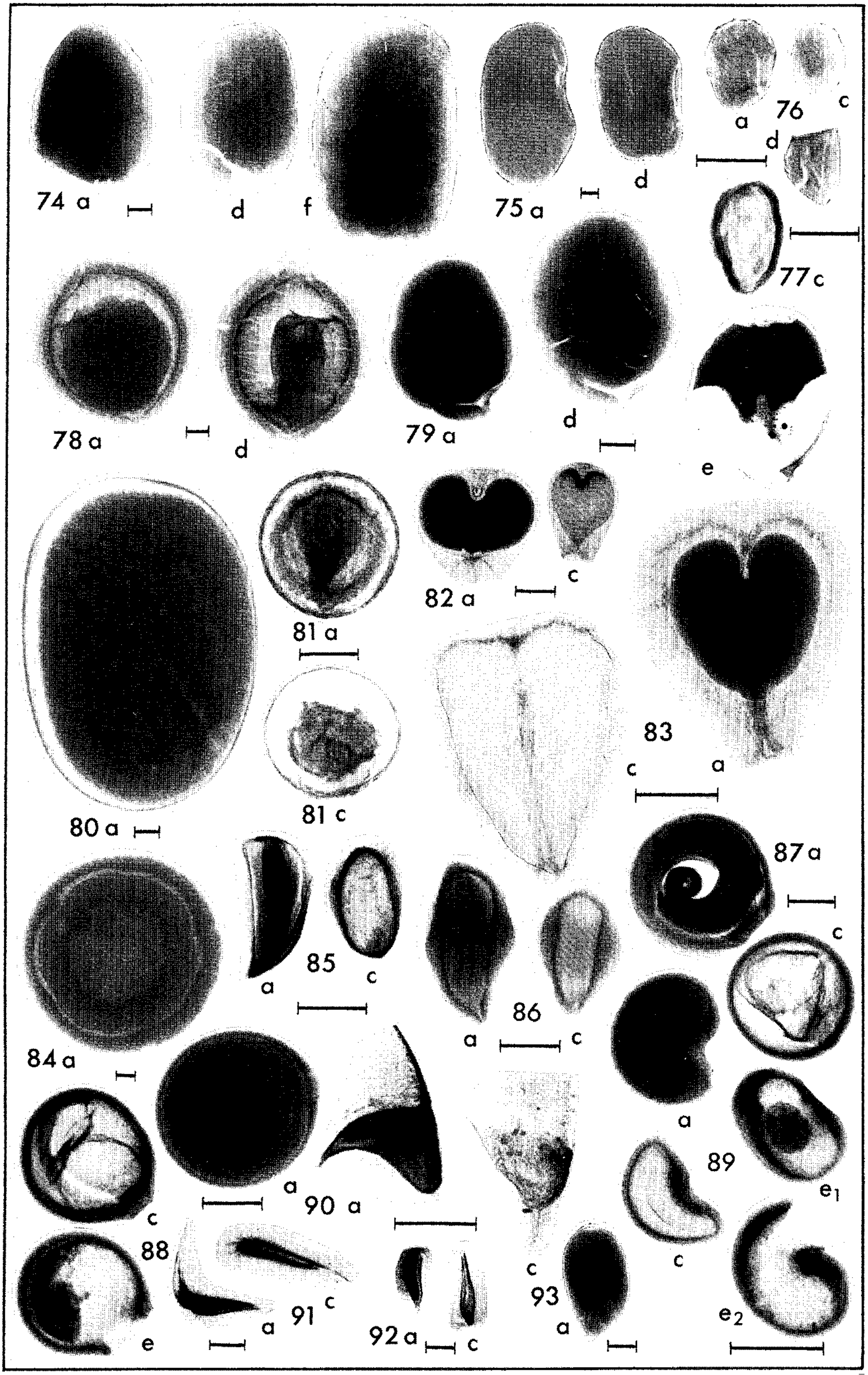
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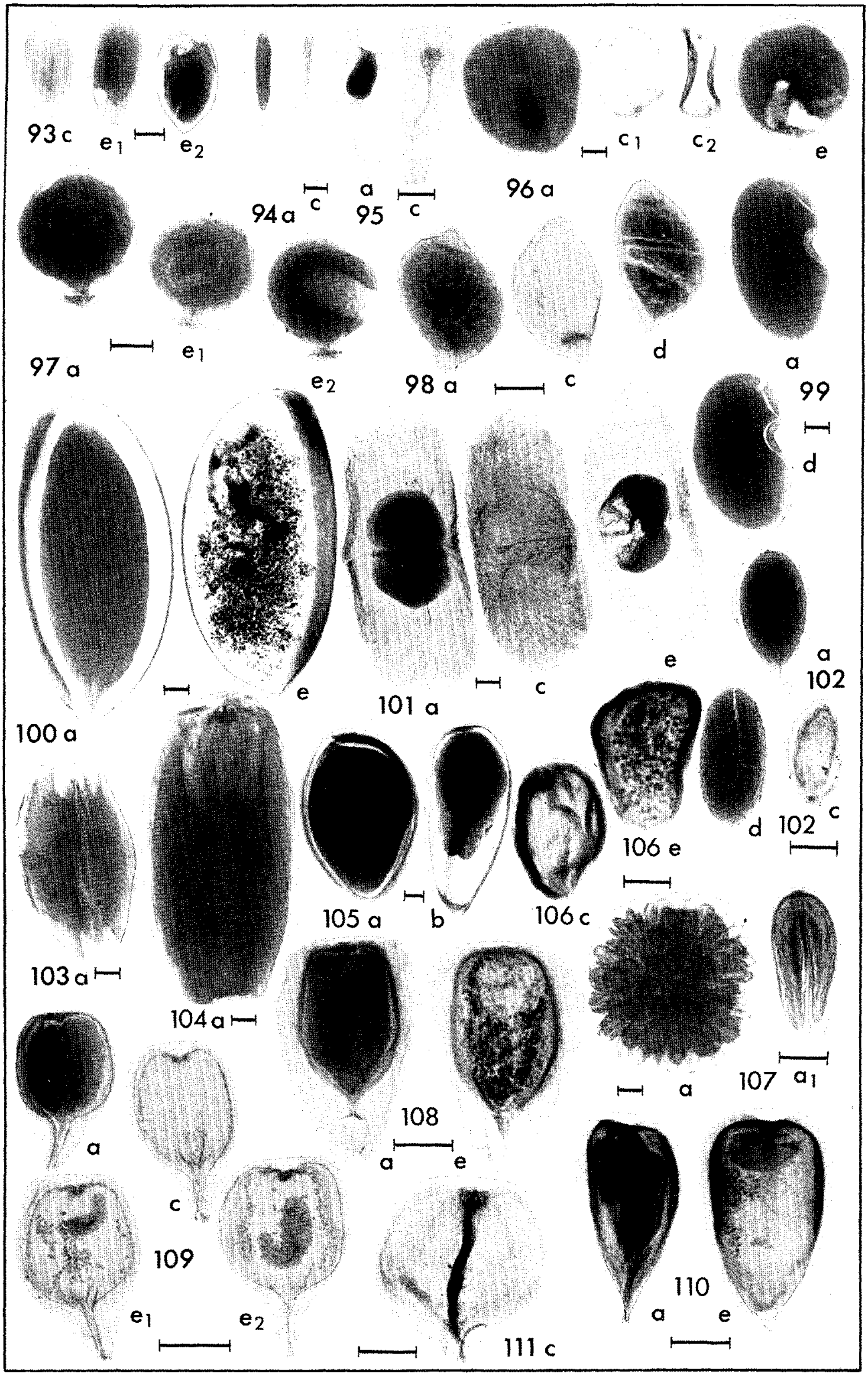
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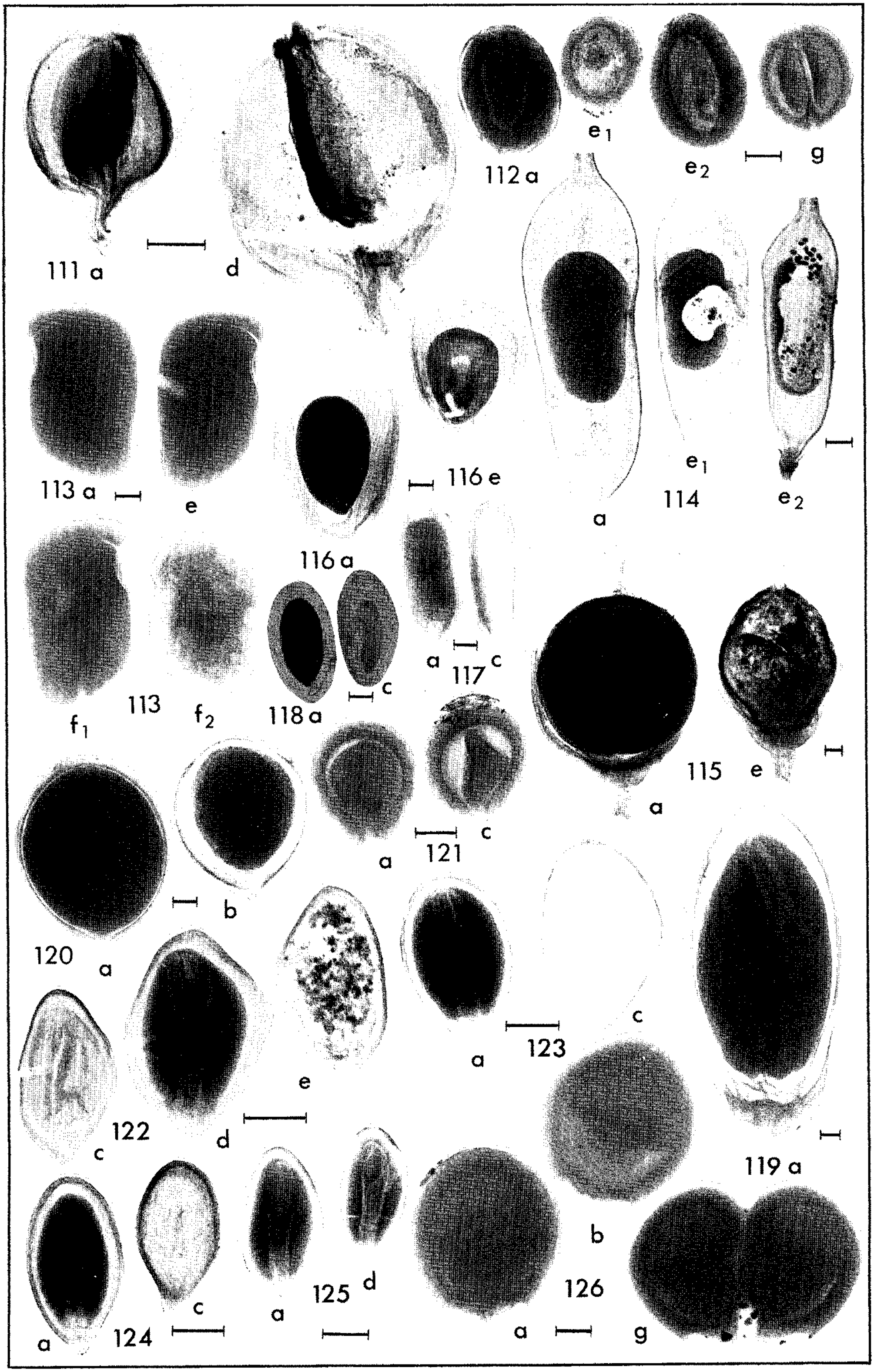
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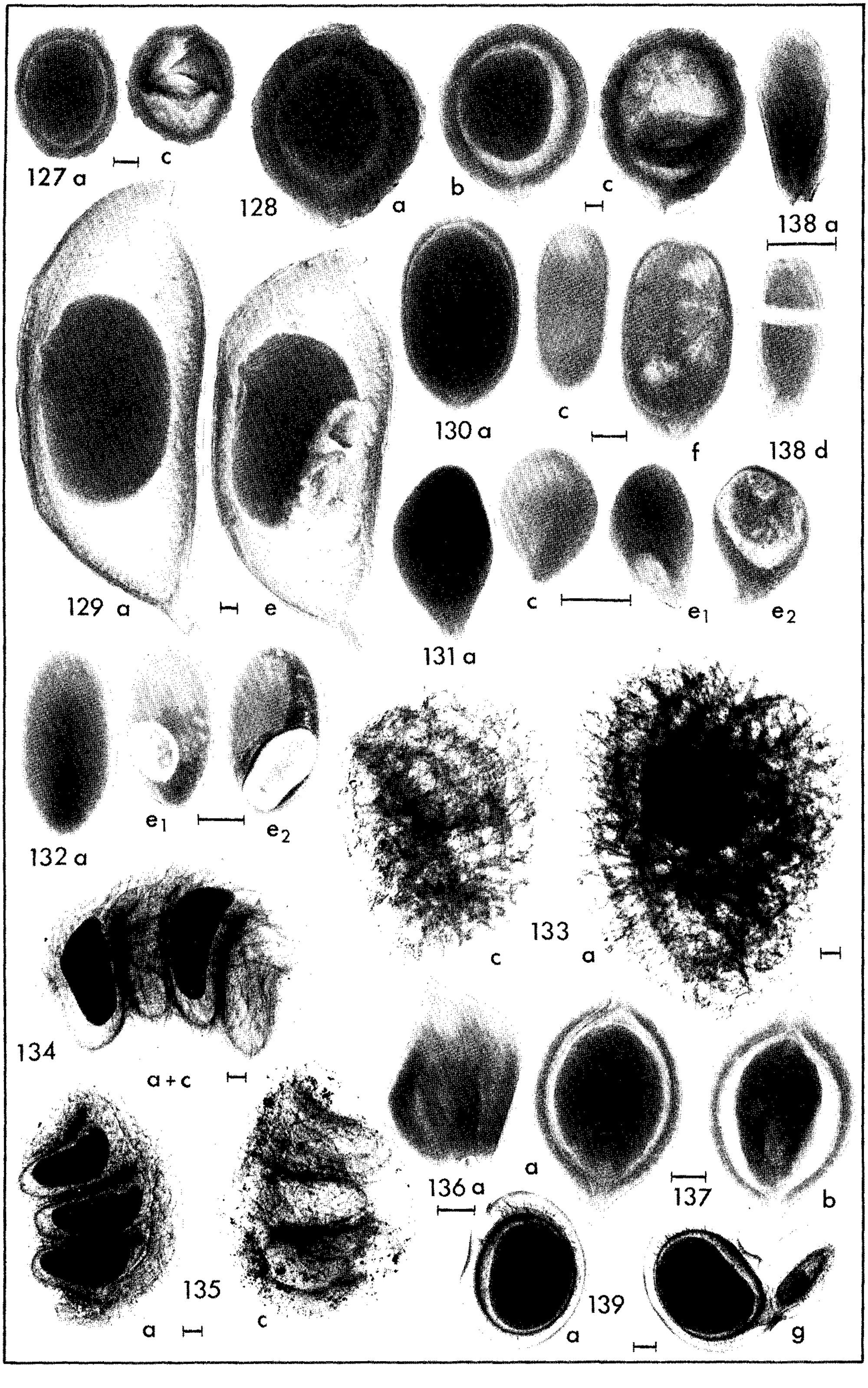
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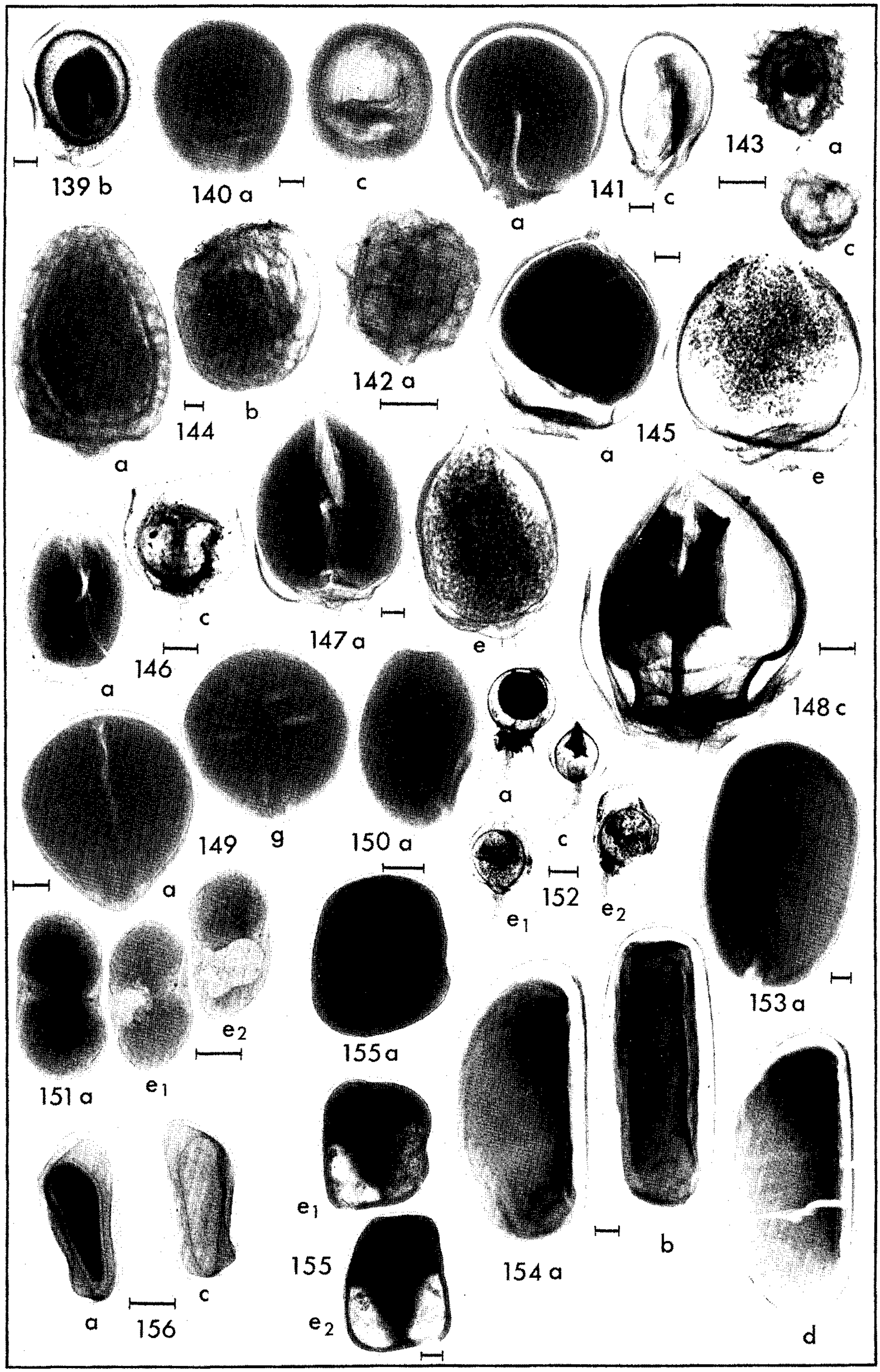

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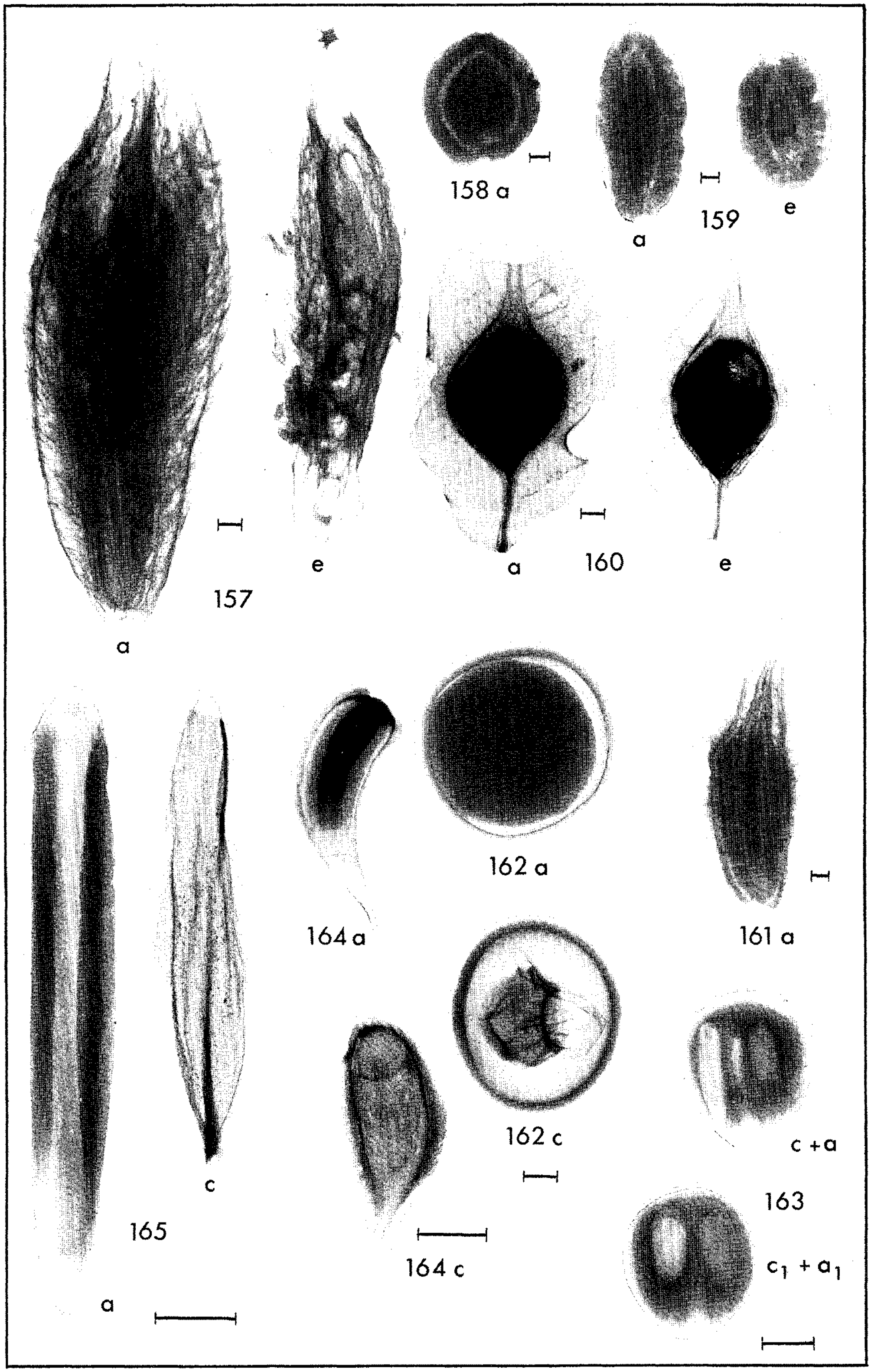
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c_1 + a_1
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164 c
165
a
c