Seed Germination of some Tropical Legumes

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An account is given of the influence of seed treatment on the germination of Calopogonium mucunoides, Centrosema pubescens, Flemingia congesta and Pueraria phaseoloides. Among the treatments studied are: storage conditions, mechanical scarification, concentrated sulphuric acid treatment, and immersion in water, glycerine and kerosene. A brief report is also given of the effects on germination of Gibrel, Kinetin and infra-red irradiation.*

Three creeping legumes, *Calopogonium mucunoides* Desv., *Centrosema pubescens* Benth. and *Pueraria phaseoloides* Benth., and the leguminous shrub *Flemingia congesta* Roxb., are extensively used as cover crops and green manures in Malayan agriculture. There is some doubt if the use of legumes for these purposes is beneficial in all circumstances. There are, however, cases where the establishment of a leguminous cover crop is the only practical solution to the problems of erosion control and the exclusion of undesirable weeds. When sown legumes are employed, establishment should be as rapid as possible in order to cover the soil before erosion can take place and before weeds can invade or regenerate.

If untreated seed is used the percentage germination is often low and establishment is uneven and slow. It has consequently become a common practice to treat leguminous cover plant seeds in one way or another with a view to improving germination. This paper is a report on experiments in which we have tested the effect on germination and establishment of various seed treatments, including conditions of storage.

CHEMICAL & MECHANICAL SCARIFICATION; LIQUID IMMERSION; STORAGE CONDITIONS

Current Practices: Sulphuric Acid and Hot Water Treatments

In Figure 1, commercial samples of seed are grouped by percentage germination with and without pretreatment (by chemical scarification) with concentrated sulphuric acid followed by washing. Pretreatment gives higher percentage germination. The difference between the germination in the two tests divided by the germination after acid treatment defines the 'hard seed fraction' or proportion of seed which will not germinate within 21 days without effective pretreatment. The hard seed fraction varies considerably (Figure 1).

In Figure 2 the cumulative germination over 21 days is given for untreated and acid treated seeds. Effective treatment increases both the percentage germination and the rate of emergence. These are beneficial effects in field practice in that seeding rates may be reduced, adequate numbers of seed will germinate even if the hard seed fraction is high, and the period of establishment is reduced.

Two methods have been used in field practice hitherto: (i) sulphuric acid pretreatment (ii) immersion in warm or hot water. In the latter method the seeds are immersed in hot water at 50°C for periods up to 16 hours or immersed in water at 70°C and left to cool. Application of the acid treatment on a large scale involves some danger to the operatives and protracted treatment can damage the interior of the seed. The hot water treatment is not always effective. For instance, the supposedly optimal hot water treatment for each species as determined in earlier work effected

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no improvement in: 19 out of 86 samples of *Calopogonium*, 25 out of 113 samples of *Centrosema*, 8 out of 14 samples of *Flemingia*, 11 out of 156 samples of *Pueraria*.

The current hot-water methods have a further disadvantage. The seeds are washed or soaked in water and unless they are rapidly dried after treatment before germination commences, the absorbed water allows germination to take place in the field even if there is inadequate moisture in the soil. Complete loss may result if rain fails after sowing. The object of these studies is to seek safe and simple methods of treating seed which will enhance the percentage germination and the rate of emergence without increasing drought susceptibility.

Effect of Storage Conditions

The testa of a fully ripened seed is impervious to water and if the path of water entry is closed the seed becomes hard. The results of the storage experiment reported in Figure 3 indicate that damp conditions increase the proportion of hard seed. Seeds were stored in a well ventilated dry room. Humidity fluctuated from 50% by day to nearly 100% at night; the temperature range was 25°C to 32°C, but usually 30°C by day and 28°C by night. These conditions are referred to hereafter as normal room conditions. Seeds of the same origin were stored in a cabinet under the same temperature conditions but in a water saturated atmosphere.

For the storage experiment, only 'good seed to the eye' were used. At monthly intervals a sample of 600 seeds of each species was withdrawn from each set of conditions and after any seed which no longer appeared good had been removed the sample was divided into halves. One half of the sample was tested for germination without further treatment and the other half set out for germination after the testa had been cut with a scalpel. This 'cutting' treatment is very effective and gives results comparable with optimum acid treatment. In all cases the germination with or without cutting treatment declined during storage. In particular, there was a marked reduction in the germination of seed which received no cutting treatment after storage under damp conditions, so that the hard seed fraction rose as a result. This is in agreement with the report (HYDE 1954) that the hard seed fraction increased in other leguminous seeds stored at a constant high humidity.

Immersion in Warm Liquids

A saturated atmosphere during storage has a depressing effect on germination without pretreatment, and immersion in hot water is not always effective as a pretreatment. Therefore immersion in other liquids was tried. Figure 4 shows the results of immersion in glycerine, water and kerosene (commercial paraffin fuel) at room temperature (28–30°C) and at 50°C. For the latter the liquids were raised to 50°C before the seeds were introduced and held at that temperature for the periods indicated. In these tests the glycerine was not washed off but was allowed to adhere to the seed; neither was it possible to remove the kerosene completely—only the excess was cleaned off. The controls were cut and uncut seed not subjected to immersion treatment.

In this and all other experiments the seeds were set out for germination on moist Whatman seed-test papers (1/16 in. thick, 9.0 cm diameter) in covered, unglazed porcelain blocks, 100 seeds per block. Germinated seeds were counted and removed daily and the papers kept moist. Emergence of the radicle was the criterion of germination. Tests ran for 21 days.

A summary of the results follows.

1. *Calopogonium*. Glycerine was effective in promoting germination, especially warm glycerine. The longer periods of immersion in warm kerosene were depressive.
2. *Centrosema*. Glycerine was effective, especially warm. Warm water and kerosene promoted germination to some extent.
3. *Flemingia*. All warm liquids were effective. Cool kerosene was effective at 40 minutes immersion.

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4. *Pueraria.* All warm liquids were effective, especially glycerine and kerosene. Cool glycerine was only slightly effective and cool kerosene was markedly effective during short periods of immersion.

In general, cool water was ineffective and warm water gave variable results. Cool glycerine was effective in certain species and warm glycerine was effective in all cases. Kerosene gave variable results, but was more effective when warm.

A further experiment was undertaken in which the seeds were immersed in kerosene and glycerine at different temperatures and left to cool for two hours. The results are given in Figure 5. Apart from a decline in most cases at the higher temperatures employed and a tendency for glycerine to be more effective than kerosene, the results may be summarised as follows:

1. *Calopogonium.* Glycerine effective.
2 *Centrosema.* Kerosene effective and glycerine very effective.
3. *Flemingia.* Kerosene and glycerine fairly effective but variable.
4. *Pueraria.* Glycerine and kerosene very effective.

Mechanical Scarification and Dry Warmth

The effects of two other treatments are illustrated in Figure 6: (i) mechanical scarification by rotation (75 r.p.m.) in a hexagonal drum, the interior lined with sand paper and (ii) the effect of dry warmth. The body of each diagram shows the effects of these treatments for various periods on one sample of seed of each species. The left hand column (B.S.) shows the results of 28 hours mechanical scarification of seed in bulk from another source for field trial. In all cases scarification for 28 hours promoted germination. Scarification for only 4 or 8 hours improved germination in *Flemingia* and *Pueraria.* Dry warmth gave variable results: it was depressive in *Flemingia,* ineffective in *Calopogonium,* just effective over a period of 2 to 8 hours in *Centrosema* and very effective in *Pueraria.*

Collation of Results

Thus far we find that treatments which cut, or chemically or mechanically scarify the testa are effective. It should be noted that scarification with sulphuric acid is also a heat treatment owing to the heat generated locally when the seeds are immersed in the acid and during the washing away of the acid with water. Dry warmth has a variable effect. Generalising, immersion in warm liquids is more effective than immersion in cool liquids and these non-acid liquids are effective in the order: water least, kerosene intermediate and variable, glycerine most effective. The pure glycerine used in these experiments has a strong osmotic concentration when in contact with aqueous systems and may owe its effectiveness to the extraction of water, which is consistent with the fact that humidity during storage depresses germination. Solution of impermeable substances by glycerine and kerosene may be a contributory factor where these liquids are effective. However, a preliminary trial with the fat solvent ethyl alcohol was not promising.

Effects of Treatments on Viability

The question arose whether the less effective treatments merely failed to promote germination or whether beneficial effects were counterbalanced by a reduction in the viability of the seed. Therefore seeds were subjected to various pretreatments discussed in the previous experiments for whatever period appeared to be optimal in those experiments. Afterwards they were set out for germination (i) without further treatment and (ii) after cutting the seed coat. The results are given in Figure 7. Despite a few anomalies (e.g. where cutting after treatment gave lower germination than treatment alone), the overall effect of pretreatments was on germination itself without affecting to any marked degree the total proportion of seed capable of germinating.

Miscellaneous Observations

Other experiments, not reported in detail here, allow us to draw the following conclusions.

Chilling seed, wet or dry for 1 to 7 days at 1 to 5°C, had a depressing effect on germination.

Immersion in a mixture of 50% glycerine and 50% water by volume had virtually the same effect as water whether cool or warm. However, a preliminary trial showed crude glycerine from the soap factory (approx. 80 – 82% glycerine, 8% common salt, remainder water and other residues) to be of equivalent effect, when used warm, to pure glycerine: thus the physical properties (osmotic concentration and temperature) of the solution may be important.

During storage, especially under damp conditions, the total viability (i.e. proportion of total seed which will germinate after cutting) declined more rapidly in scarified and warm-glycerine treated seed than in untreated seed. This deterioration was greatest for glycerine treated seeds. However, scarification and warm glycerine treatment decreased the proportion of hard seed and this fraction remained almost constant for seed so treated during storage under normal or damp conditions. Thus, despite the general decline in percentage germination, seed do not apparently become 'hard' again after these treatments. It is advisable to use seed soon after treatment, although scarified seed was stored for two months and glycerine-treated seed for one month without severe deterioration.

The total viability of untreated seed was maintained without increase in hard seed fraction during a storage period of over eighteen months in a dehumidified room (relative humidity 50 – 55%).

No differences have been detected between germination in covered, unglazed, porcelain blocks and in glass petri dishes, i.e. exposing the germinating seed to daylight does not appear to influence germination. Germination proceeds at the same rate in an air conditioned room in which the temperature is reduced to 23°C for 8 hours each day as in a room where normal conditions prevail, i.e. within these limits ambient temperature during germination has little effect.

Pot and Field Trial of Promising Methods

Table 1 shows results for a pot experiment on the effects of pretreatments on germination, growth and nodulation. The experimental design was factorial without replications: 4 species × 4 pretreatments × 8 combinations of seed dressings. Only pretreatment effects are considered here. Plants were harvested three months after sowing.

The results of a field trial to study the effect of pretreatments on the establishment of the legumes are shown in Table 2. A replicated factorial design was used: 4 species × 4 pretreatments × 16 combinations of seed dressings × 4 replications. Only pretreatment effects are considered. Each plot was a 38 ft length of drill, 4 ft from either adjoining drill. Observation was at three months after planting and a score of 0 to 5 was given for general appearance. The number of plants in the central foot of each drill was counted and their spread outwards from the centre of the drill was measured in inches.

The optimum treatments for each species determined in previous experiments were applied. The warm kerosene treatment was included in the pot experiment because, although this was not the most promising of treatments, it was much less expensive than glycerine. In the future the use of the cheaper crude glycerine may provide a solution to the cost problem. The greater weights of plants and nodules obtained after acid and warm glycerine treatment may be attributed largely to accelerated emergence, although there were various interactions. For instance all pretreatments lead to an increased weight of plants and nodules in *Pueraria* and the converse in *Flemingia*. The field trial confirms the value of warm glycerine and scarification methods for establishing the creepers and of scarification for *Flemingia*.

The warm glycerine and sulphuric acid treatments are effective on certain species which do not respond to mechanical scarification, for instance *Stylosanthes guyanensis* (Aubl.) Sw., whose seed is protected by the fruit pod, and *Clitoria rubiginosa* Juss. ex

Pers. whose seed is sticky. The inconvenience of the glycerine adhering to seeds is overcome and turned to practical value by mixing in ground rock phosphate with the seed to absorb the glycerine. The result is excellent placement of this most essential fertiliser for the establishment of legumes on Malayan soils.

GIBREL AND KINETIN

Recently there has been widespread interest in the properties of gibberellins and 6-(substituted) purine compounds. For instance SKINNER *et al.* (1958) have reported on the effects of these substances on lettuce, grass and clover seed germination. The results of an experiment using Gibrel are given in Table 3. Untreated seed and cut seed were set out for germination on the Whatman seed-testing papers soaked in 15 ml of solutions of appropriate strength. There were 100 seeds in each covered, unglazed porcelain block, and five blocks per treatment. The seeds were watered daily to maintain moist conditions, but the solutions were not washed away.

The results show no improvements of practical importance by Gibrel treatment. The improvement due to cutting was highly significant throughout. Only in the case of *Flemingia* seed which had already been cut was there any consistent, significant enhancement of germination by Gibrel treatment; some improvement in germination of uncut *Flemingia* seed was also obtained but it was not significant. In *Calopogonium*, 10 p.p.m. Gibrel depressed the germination of cut seed, probably significantly ($P = 0.05$), although this concentration gave the highest germination of uncut seed; the reverse results were obtained in *Centrosema* and *Pueraria*. Plotting the cumulative germination daily gave no evidence of accelerated or retarded rate of germination due to Gibrel. Cutting accelerated germination in all cases.

The results of a further test to see whether there is any synergistic effect of Gibrel and Kinetin on otherwise untreated seed are given in Table 4. Three seed germination blocks with Whatman seed-test papers wetted with 15 ml of solutions of appropriate strength were used for each treatment, 100 seeds per block. After setting the seed, the moisture was maintained by watering daily, but the solutions were not washed away. Cut seeds, not treated with Gibrel or Kinetin, were provided as a control to show the potential germination. Only in the case of *Centrosema* were the responses to 10 p.p.m. Gibrel and 10 p.p.m. Kinetin probably significant, but these small improvements were not of practical importance. No effect of Gibrel or Kinetin on the rate of germination could be detected.

INFRA-RED LAMP IRRADIATION

Finally, the effects of irradiation with infra-red lamps were tested. The lamps available were Philips Infraphil Type 13373F/479 (150 watts) and Osram IRR 4892 (250 watts). The lamps were suspended about 65 cm vertically above the seed, which were in open dishes near the centre of the light cone. The light was not filtered. The Philips lamp gives a relatively narrow cone of red and infra-red light; the air temperature below the lamp is about 36°C but thermometers in the position of the seeds record temperatures up to 50°C. The Osram lamp gives a wide cone of illumination, which appears to be a white light but extends into the infra-red; the ambient temperature below the lamp is about 35°C and thermometers in the position of the seeds record temperatures up to 43°C. These figures refer to stable conditions after the lamps have been burning for some hours.

According to information supplied by the makers, the total radiant energy at the position of the seeds is about 60 milliwatts per square centimetre and 35 to 45 mW/cm^2 under the Philips and Osram lamps respectively. Certain wavebands have been found to affect germination in other species. These are blue (about 0.45 microns—slightly inhibitory), red (about 0.67 microns—stimulatory) and near infra-red (about 0.73 microns—inhibitory); the Osram lamp transmits relatively more visible light than the Philips lamp. For instance, the latter does not emit any blue at

all. However, the Philips radiates relatively slightly more of the heating infra-red and under the conditions of the experiment much more in absolute units than the Osram—as the details given above indicate.

After the attainment of stable conditions, seeds were exposed to the lamps separately for periods from 7½ minutes to 64 hours and afterwards transferred to germination blocks. The results are given in Figure 8. In the three creeping species there was a tendency for the shorter periods of irradiation to depress germination, and this depression reached significance (P = 0.01) at certain points for *Calopogonium* and *Pueraria*. However, longer periods of irradiation reversed this effect. Significantly improved germination was obtained by 8 hours Philips irradiation of *Calopogonium*, by 16 or more hours Osram irradiation of *Calopogonium* and *Centrosema*, by 2 hours with Osram on *Pueraria* and 1 hour or more with Philips on *Pueraria*. Possibly certain wavebands of light had a depressing effect which was countered by the warming effect of longer exposure in these species; dry warmth promoted germination in *Centrosema* and did so markedly in *Pueraria*.

BORTHWICK *et al.* (1952) have reported promotion of lettuce seed germination by red light and inhibition by infra-red: such processes may be involved here, but the wide spectra from our unfiltered lamps preclude further inferences at present.

The irradiation of *Flemingia* seed for the shortest period used (7½ minutes) resulted in a marked improvement in germination which was confirmed for the Philips lamp in a second test (upper graph), in which the germination was even better than that of cut seed in certain instances. Compared with the other species the contrast was striking, especially because *Flemingia* seed germination was depressed by dry warmth, although usually enhanced by immersion in warm liquids. The only other instances where there has been evidence of germination superior to that of cut but otherwise untreated seeds were for cut seeds of *Centrosema* treated with 10 p.p.m. Gibrel and for cut seeds of *Flemingia* treated with 1, 10 and 100 p.p.m. Gibrel. It may be premature to draw conclusions at this stage, but the behaviour of *Flemingia* seed differs in several ways from that of the other species studied. Although *Flemingia* conforms with them in that impermeability appears to be the main factor involved in 'hardness' of seed, there are traces of other physiological processes.

DISCUSSION

Mechanical and chemical scarification of leguminous seeds to improve germination are long established practices. Sulphuric acid scarification of lupine seeds has been shown (BURNS 1959) to erode pits through the testa, or to hydrolyse the counter palisades of the hilum so that they can no longer close the hilar fissure when there is moisture outside the seed in excess of that within. The external humidity and internal moisture content of leguminous seeds have been investigated (HYDE 1954) in relationship to opening and closing of the hilar fissure. The improvement of germination by scarification and the increase in hard seed fraction during storage in constant damp conditions indicate that similar processes are probably involved in the four species studied here, namely the impermeability of the testa in fully ripened seed and the control of the normal path of water entry by a hydrostatic mechanism. Improvements in germination by immersion in glycerine can be explained by such hydrostatic considerations.

Dry warmth promoted germination in *Centrosema* and *Pueraria* and heat enhanced the effects of liquids in all species. Apart from the anomalous depression of germination by dry warmth in *Flemingia*, warmth in some form appears to be beneficial in all species. The effect of warmth may be by action on a bi-layered mechanism such as the hilar palisade.

Recently, interest has centred upon such substances as gibberellins and 6-(substituted) purines, for example Kinetin. GRAY (1957) reported accelerated germination of beans and peas by application of gibberellin slurries.

SKINNER *et al.* (1958) found increased germination in white clover in response to Kinetin but not to Gibrel. We have detected only relatively minor responses to either Gibrel or Kinetin in the four tropical species studied.

In that wide spectra were permitted, our irradiation of seeds by infra-red lamps has not been critical. An improvement in germination was effected by long periods of irradiation in the creeping species, which may be explained by heat adsorption. There was also evidence in these species of depressing effects after short periods of irradiation, but similar short periods stimuated an improvement in the germination of *Flemingia*. These experiments indicate that infra-red (or other radiations) may have physiological effects on seed of these species.

A number of anomalies arose. For example, immersion in glycerine for two hours at room temperature, approx. 30°C by day, (Figure 4) was really the same treatment as immersion in glycerine at 30°C for two hours (Figure 5), yet the latter would appear to be much more effective in promoting germination of *Centrosema* seed. In the experiment illustrated in Figure 7, immersion of *Flemingia* and *Pueraria* seed in cold kerosene for 40 minutes failed to reproduce the enhancement found in the experiment to which Figure 4 relates; moreover, scarification was not effective on *Pueraria* in this instance. In view of the variability of hot water treatment mentioned in the introduction, especially with respect to *Flemingia*, the good response of this species in the experiments (Figure 4 and 7) is perhaps surprising. The results in Table 3 show that 10 p.p.m. Gibrel probably depressed germination of uncut *Centrosema* and *Pueraria* seed significantly, yet there is no evidence of this in Table 4 but rather the converse. Neither do the tests of infra-red lamp irradiation on *Flemingia* seed agree completely. Nevertheless, most of these effects mentioned could be established as significant in each individual experiment.

In each individual experiment every effort was made to use uniform 'good' seed from one source. However, the anomalies noted above, the variability in response of commercial samples to hot water treatment and the variability in hard seed fraction itself must serve as warnings that no two populations of seed necessarily consists of similar proportions of seeds in the same physiological condition. At present we have no inbred lines or horticultural varieties in these species which might be less variable than the present supply, nor can we guarantee that all samples of seed have the same history. We must treat these investigations as exploratory at this stage.

SUMMARY

1. Storage under constant damp conditions depresses the total viability and increases the hard seed fraction in *Calopogonium mucunoides, Centrosema pubescens, Flemingia congesta* and *Pueraria phaseoloides*.

2. Scarification, mechanically, by cutting and by concentrated sulphuric acid, promotes germination in all four species.

3. Dry warmth promotes germination in *Pueraria* and to a lesser extent in *Centrosema*. Immersion in warm liquids, especially glycerine, promotes germination. Cool glycerine improves germination to some degree in many cases.

4. The above phenomena are explicable on the assumption that a hard seed has an impermeable testa and that water enters by a path which is hydrostatically controlled.

5. Treatments (2) and (3), above, do not seem to have any marked effect on the viability of the seed but only to effect its germination, in contrast to damp storage. See (1) above.

6. Only minor responses to Gibrel and Kinetin have been detected.

7. Irradiation with unfiltered infra-red lamps suggests that some radiations may depress germination in three species, but this process is reversed by longer periods of irradiation, probably owing to heating effects. *Flemingia* showed a marked response to comparatively brief irradiation.

8. In their responses to damp storage, scarification and immersion in cool or warm liquids, there is considerable agreement between the four species. However, *Flemingia congesta* differs to a certain extent from the other species in its response to dry warmth, Gibrel and infra-red lamp irradiation.

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TABLE 1. EFFECT OF SEED PRETREATMENT ON GERMINATION, PLANT SIZE AND NODULATION. POT EXPERIMENT

Pretreatment	Percentage germination					Dry wt* whole plants, grams					Dry wt* nodules, grams				
	C.m.	C.p.	F.c.	P.p.	Means	C.m.	C.p.	F.c.	P.p.	Means	C.m.	C.p.	F.c.	P.p.	Means
Untreated	25.4	54.7	75.5	39.0	48.7	59.9	88.1	40.5	55.9	61.1	1.89	4.31	1.07	3.56	2.71
Acid treated	23.5	82.3	54.5	82.1	60.6	77.7	98.7	37.9	81.9	74.1	1.84	4.90	0.81	7.01	3.64
Hot glycerine	35.0	80.3	74.9	75.4	66.4	80.1	89.8	35.4	78.5	71.0	1.87	4.59	0.92	4.34	2.93
Hot kerosene	17.1	50.8	80.8	49.8	49.6	63.9	64.7	31.8	61.9	55.6	1.56	3.86	0.80	4.44	2.66
Means	25.3	67.0	71.4	61.6		70.4	85.3	36.4	69.6		1.79	4.41	0.90	4.83	

* Weights refer to 10 plants

s.e. any pair of interaction means	± 3.05	± 4.30	± 0.177
s.e. any pair of main effect means	± 1.53	± 2.15	± 0.089
min. 5% sig. diff. any pair of interaction means	8.6	12.1	0.50
min. 5% sig. diff. any pair of main effect means	4.3	6.1	0.25

C.m. *Calopogonium mucunoides* C.p. *Centrosema pubescens* F.c. *Flemingia congesta* P.p. *Pueraria phaseoloides*

TABLE 2. EFFECT OF SEED TREATMENT ON GENERAL APPEARANCE, ESTABLISHMENT AND SPREAD OF COVER PLANTS, THREE MONTHS AFTER SOWING. FIELD EXPERIMENT

Pretreatment	Score for appearance					No. of plants per foot					Spread in inches				
	C.m.	C.p.	F.c.	P.p.	Means	C.m.	C.p.	F.c.	P.p.	Means	C.m.	C.p.	F.c.	P.p.	Means
Untreated	2.9	2.8	2.9	3.5	3.0	3.6	2.9	6.8	6.0	4.8	12.9	11.6	5.8	11.9	10.6
Acid treated	3.6	3.2	2.3	3.4	3.1	3.9	3.0	2.7	4.4	3.5	21.2	19.2	5.0	15.9	15.3
Hot glycerine	3.6	3.6	3.0	3.8	3.5	4.3	4.2	5.7	6.5	5.2	21.3	15.6	6.4	16.5	15.0
Scarified	3.4	3.3	3.1	3.4	3.3	4.0	4.1	7.5	6.3	5.5	18.0	13.3	6.8	17.2	13.8
Means	3.4	3.2	2.8	3.5		4.0	3.6	5.7	5.8		18.3	15.0	6.0	15.4	

s.e. any pair of interaction means	± 0.135	± 0.395	± 1.504
s.e. any pair of main effect means	± 0.068	± 0.198	± 0.752
min. 5% sig. diff. any pair of interaction means	0.4	1.1	4.2
min. 5% sig. diff. any pair of main effect means	0.2	0.5	2.1

C.m. *Calopogonium mucunoides* C.p. *Centrosema pubescens* F.c. *Flemingia congesta* P.p. *Pueraria phase oloides*

TABLE 3. EFFECT OF GIBREL SOLUTIONS AND CUTTING ON GERMINATION. 5 × 100 SEEDS PER TREATMENT

Cutting treatment	(a) *Calopogonium mucunoides*										(b) *Centrosema pubescens*									
	Percentage germination					Transformed to degrees					Percentage germination					Transformed to degrees				
	Gibrel p.p.m.					Gibrel p.p.m.					Gibrel p.p.m.					Gibrel p.p.m.				
	0	1	10	100	Means	0	1	10	100	Means	0	1	10	100	Means	0	1	10	100	Means
Uncut	39.2	41.6	44.2	37.2	40.6	38.76	40.16	41.65	37.56	39.53	35.2	36.2	28.0	37.0	34.1	36.35	36.98	31.91	37.45	35.67
Cut	96.4	96.0	94.0	94.4	95.2	79.27	78.53	75.94	76.56	77.58	79.8	84.4	87.2	83.4	83.7	63.45	67.32	69.22	66.01	66.50
Means	67.8	68.8.	69.1	65.8	—	59.01	59.34	58.80	57.06	—	57.5	60.3	57.6	60.2	—	49.90	52.15	50.56	51.73	—

s.e. of difference between any pair of interaction means ± 1.518 degrees ± 2.387 degrees
s.e. of difference between means for cut and uncut seeds ± 0.762 „ ± 1.193 „
s.e. of difference between any pair of means for Gibrel levels ± 1.074 „ ± 1.688 „
min. 5% sig. diff. between means for cut and uncut seeds 1.55 „ 2.43 „
min. 5% sig. diff. between means for Gibrel levels 2.19 „ 3.44 „

10 p.p.m. probably depresses cut seeds significantly, cf. 0 p.p.m. (but highest value on uncut not significant)

10 p.p.m. probably depresses uncut seeds significantly, cf. 1 and 100 p.p.m.
10 p.p.m. probably enhances cut seeds significantly, cf. 0 p.p.m.

In all cases the effect of cutting is significant

TABLE 3 *(Continued).* EFFECT OF GIBREL SOLUTIONS AND CUTTINGS ON GERMINATION. 5 × 100 SEEDS PER TREATMENT

Cutting treatment	(c) *Flemingia congesta*										(d) *Pueraria phaseoloides*									
	Percentage germination					Transformed to degrees					Percentage germination					Transformed to degrees				
	Gibrel p.p.m.					Gibrel p.p.m.					Gibrel p.p.m.					Gibrel p.p.m.				
	0	1	10	100	Means	0	1	10	100	Means	0	1	10	100	Means	0	1	10	100	Means
Uncut	66.8	71.8	68.8	66.8	68.6	54.85	57.97	56.12	54.91	55.96	34.2	28.8	25.2	29.2	29.4	35.73	32.34	30.06	32.70	32.71
Cut	86.2	94.4	93.0	92.8	91.6	68.83	76.34	74.76	74.61	73.63	97.2	97.0	98.2	97.4	97.5	80.71	80.46	83.49	80.87	81.38
Means	76.5	83.1	80.9	79.8	—	61.84	67.16	65.44	64.76	—	65.7	62.9	61.7	63.3	—	58.22	56.40	56.78	56.78	—

s.e. of difference between any pair of interaction means ± 2.253 degrees ± 2.061 degrees
s.e. of difference between means for cut and uncut seeds ± 1.126 „ ± 1.031 „
s.e. of difference between any pair of means for Gibrel levels ± 1.593 „ ± 1.457 „
min. 5% sig. diff. between means for cut and uncut seeds 2.30 „ 2.10 „
min. 5% sig. diff. between any pair means for Gibrel levels 3.25 „ 2.97 „

Gibrel enhances germination, particularly on cut seeds, for which 1 p.p.m. is significant and 10 and 100 p.p.m. are probably significant, cf. 0 p.p.m. Note declining trend with increasing Gibrel concentration.

10 p.p.m. depresses uncut seeds, significantly, cf. 0 p.p.m. (but highest value on cut not significant)

In all cases the effect of cutting is highly significant

TABLE 4. EFFECT OF GIBREL AND KINETIN SOLUTIONS ON GERMINATION OF OTHERWISE UNTREATED SEED, 3 × 100 SEEDS PER TREATMENT

Kinetin p.p.m.	(a) *Calopogonium mucunoides*								(b) *Centrosema pubescens*							
	Percentage germination				Transformed to degrees				Percentage germination				Transformed to degrees			
	Gibrel p.p.m.				Gibrel p.p.m.				Gibrel p.p.m.				Gibrel p.p.m.			
	0	10	100	Means	0	10	100	Means	0	10	100	Means	0	10	100	Means
0	32.8	32.6	33.3	32.9	34.9	34.8	35.3	35.0	33.6	36.3	31.0	33.6	35.4	37.1	33.8	35.4
1	37.3	33.9	32.0	34.4	37.7	35.6	34.5	35.9	31.6	40.3	37.9	36.6	34.2	39.4	38.0	37.2
10	32.6	32.8	37.6	34.3	34.8	34.9	37.8	35.9	34.3	38.7	41.0	37.9	35.9	38.5	39.8	38.0
Means	34.2	33.1	34.3		35.8	35.1	35.9		33.2	38.4	36.6		35.2	38.3	37.2	

s.e. any pair of interaction means ± 1.92 degrees
s.e. any pair of main effect means ± 1.11 „
min. 5% sig. diff. of main effect means 3.3 „

Germination of cut seed = 84.7% or 66.9 degrees

s.e. any pair of interaction means ± 1.47 degrees
s.e. any pair of main effect means ± 0.85 „
min. 5% sig. diff. of main effect means 2.5 „

Germination of cut seed = 79.0% or 62.8 degrees

TABLE 4 *(Continued)*. EFFECT OF GIBREL AND KINETIN SOLUTIONS ON GERMINATION OF OTHERWISE UNTREATED SEED, 3 × 100 SEEDS PER TREATMENT

Kinetin p.p.m.	(c) *Flemingia congesta*								(d) *Pueraria phaseoloides*							
	Percentage germination				Transformed to degrees				Percentage germination				Transformed to degrees			
	Gibrel p.p.m.				Gibrel p.p.m.				Gibrel p.p.m.				Gibrel p.p.m.			
	0	10	100	Means	0	10	100	Means	0	10	100	Means	0	10	100	Means
0	31.0	31.6	33.3	32.0	33.8	34.2	35.3	34.4	67.3	69.1	73.7	70.1	55.1	56.2	59.2	56.8
1	29.0	32.3	29.3	30.2	32.6	34.6	32.8	33.3	75.0	74.5	64.4	71.4	60.0	59.7	53.4	57.7
10	31.6	27.0	30.2	29.6	34.2	31.3	33.4	33.0	66.5	72.4	64.5	67.8	54.6	58.3	53.4	55.4
Means	30.5	30.3	30.9		33.5	33.4	33.8		69.7	72.0	67.6		56.6	58.1	55.3	

s.e. any pair of interaction means ± 1.50 degrees
s.e. any pair of main effect means ± 0.86 „
min. 5% sig. diff. of main effect means 2.6 „

Germination of cut seed = 91.0% or 72.7 degrees

s.e. any pair of interaction means ± 1.81 degrees
s.e. any pair of main effect means ± 1.05 „
min. 5% sig. diff. of main effect means 3.1 „

Germination of cut seed = 92.3% or 73.9 degrees

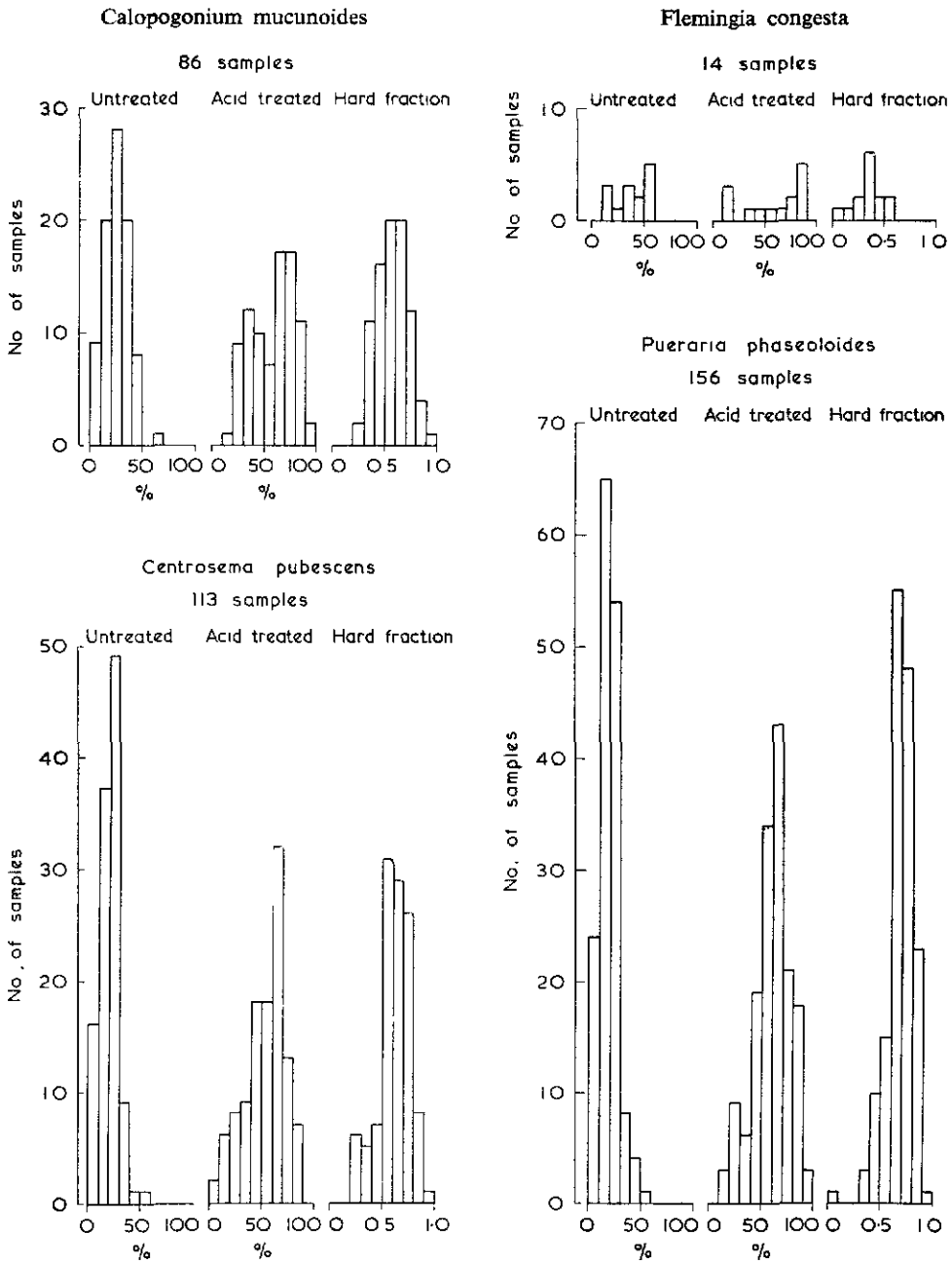

Figure 1. Numbers of commercial samples grouped according to percentage germination with and without acid pretreatment. Also the 'hard seed fraction'. 500 seeds per sample subjected to each test.

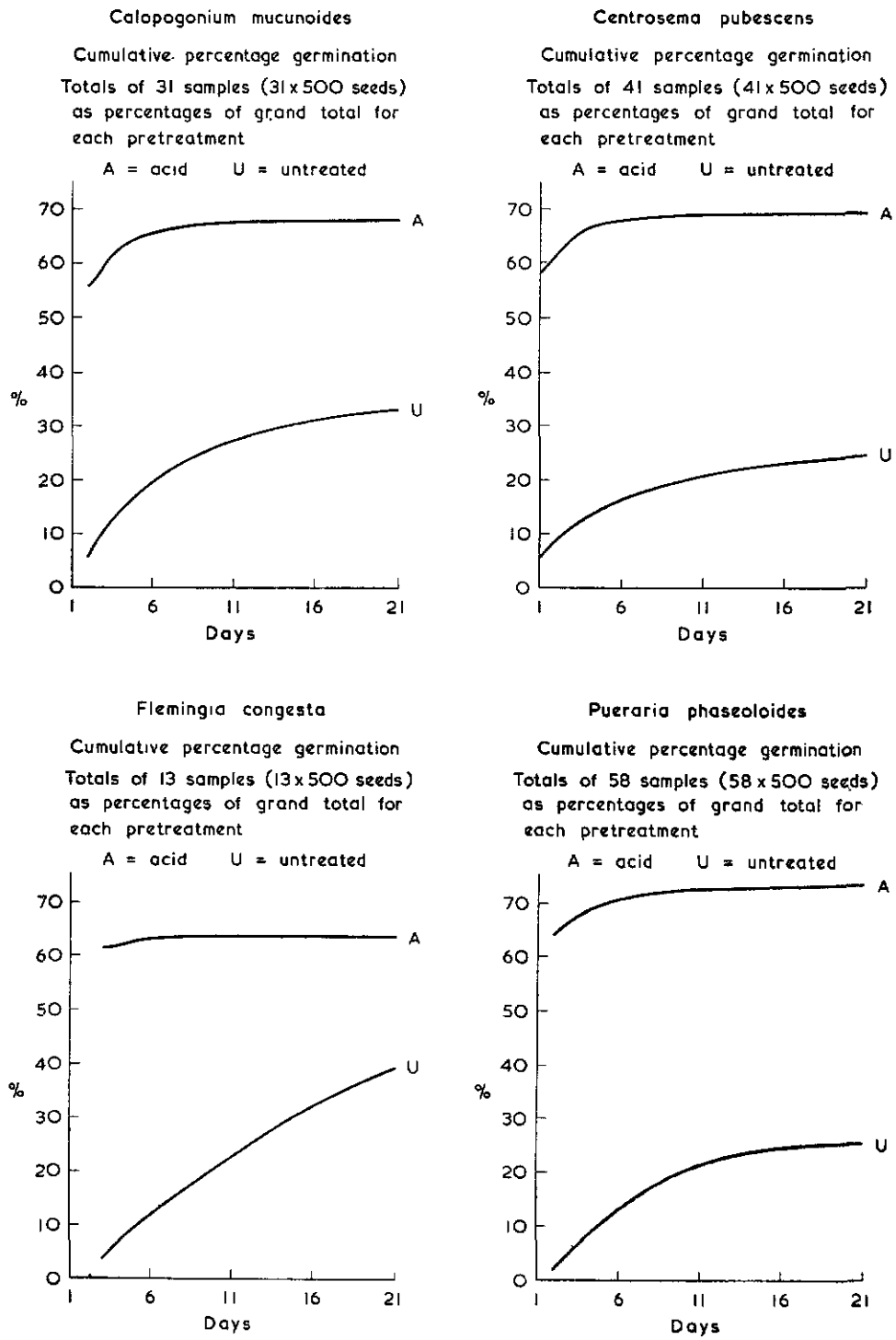

Figure 2. Cumulative germination over 21 days of untreated and acid treated seed samples.

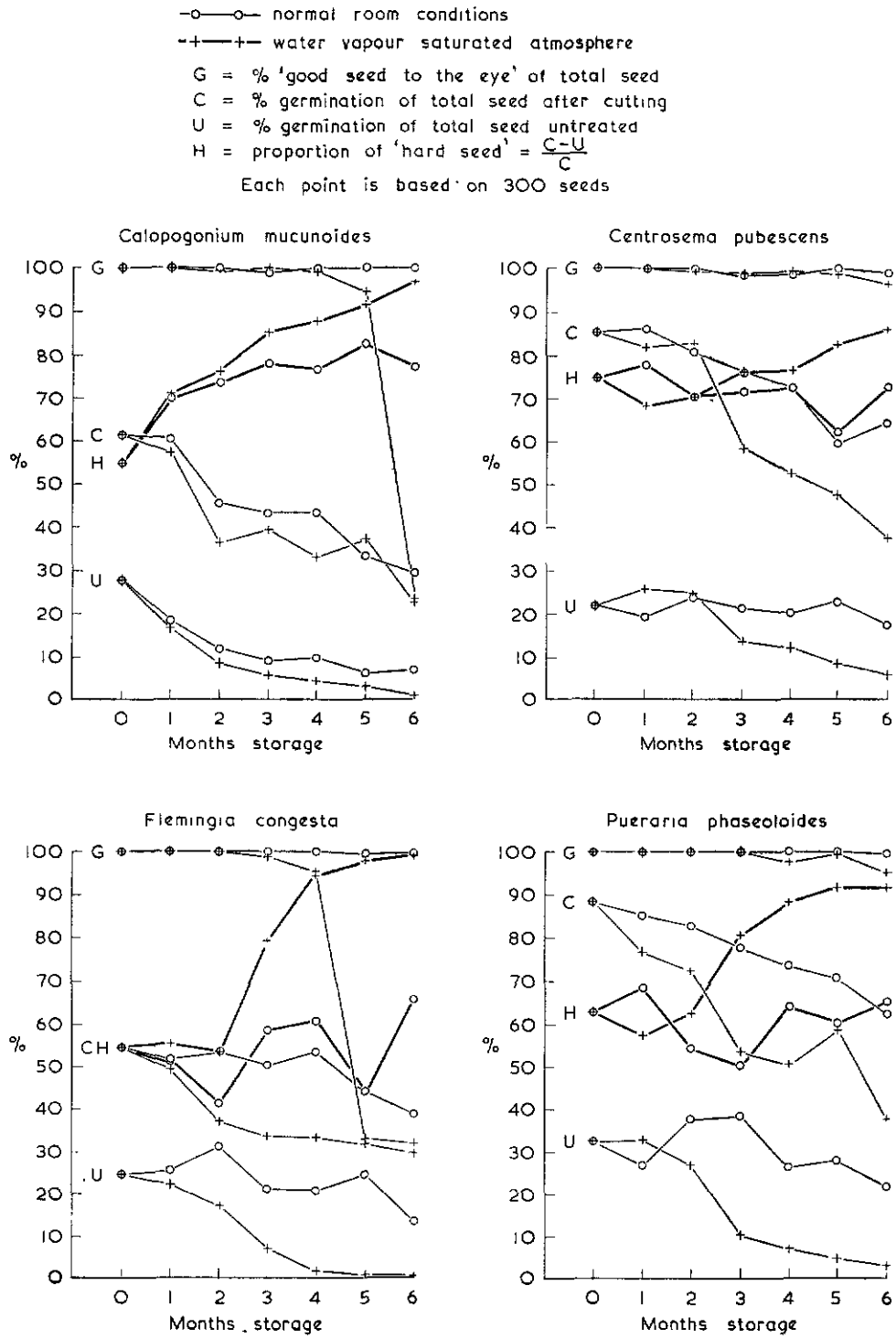

Figure 3. Storage of seed under normal room conditions and in a humid atmosphere.

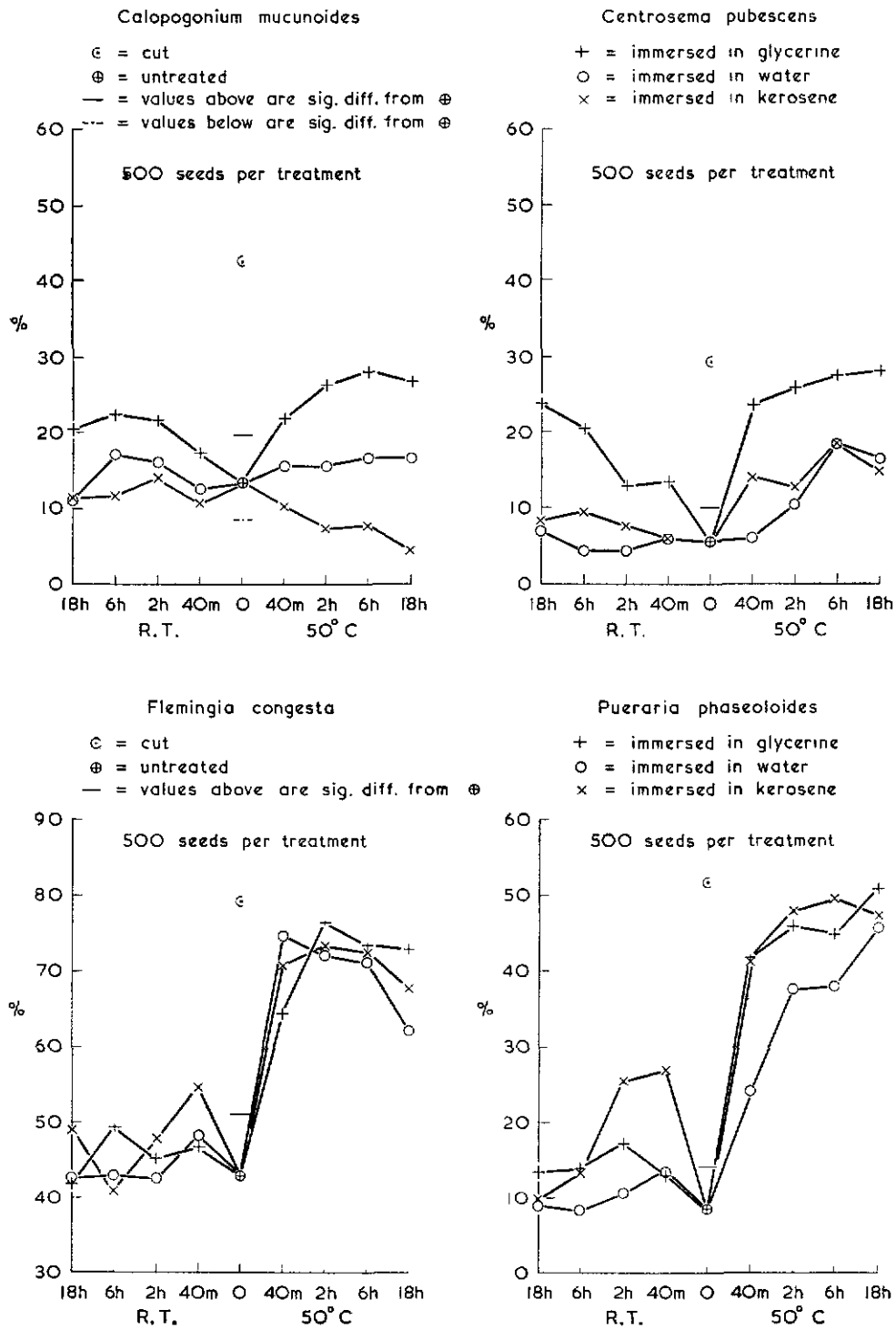

Figure 4. Effect on germination of immersion of seeds in three liquids at two different temperatures.

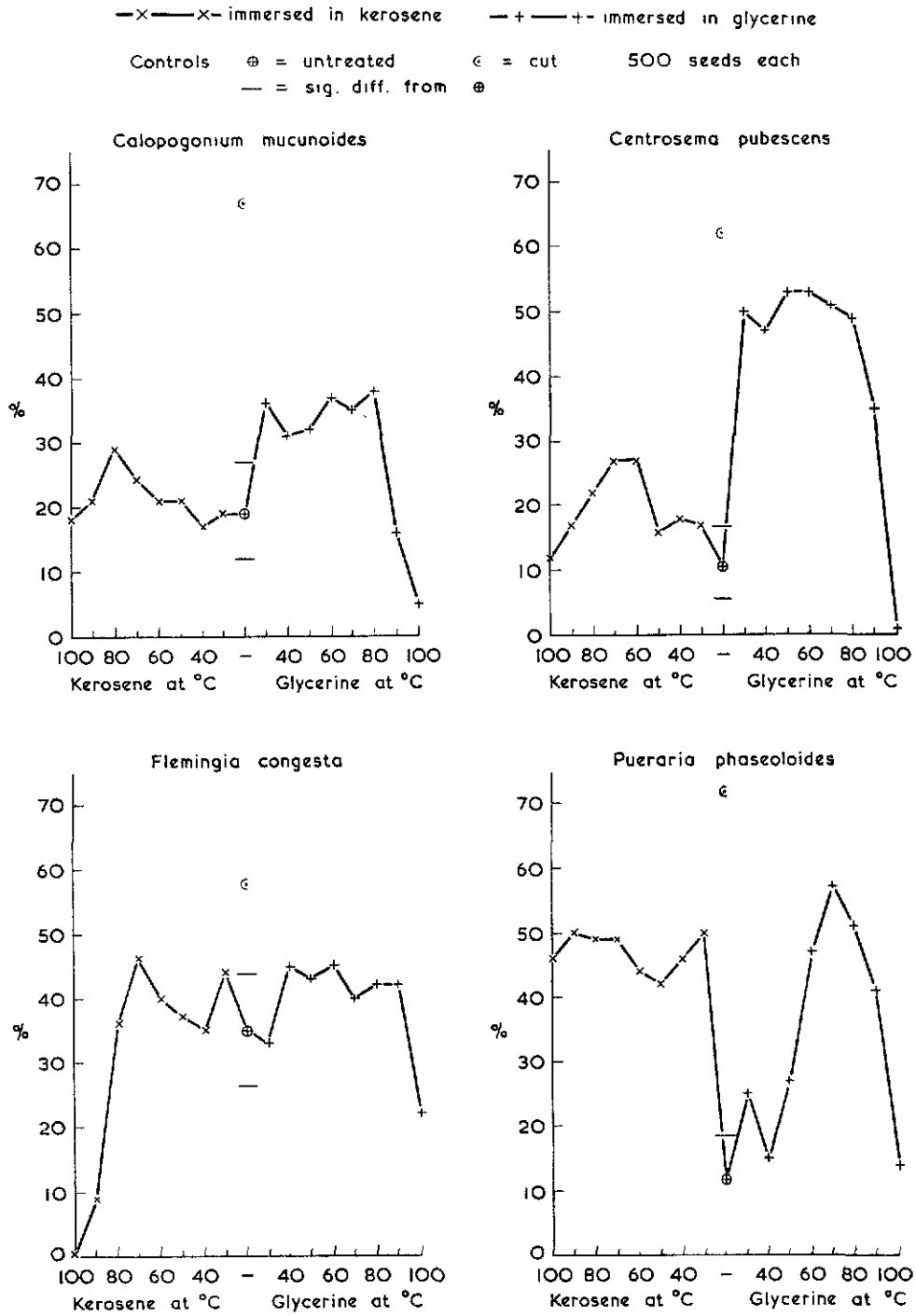

Figure 5. Effect on germination of immersion of seeds in liquids at various temperatures followed by cooling in the liquid for 2 hours. 300 seeds per treatment.

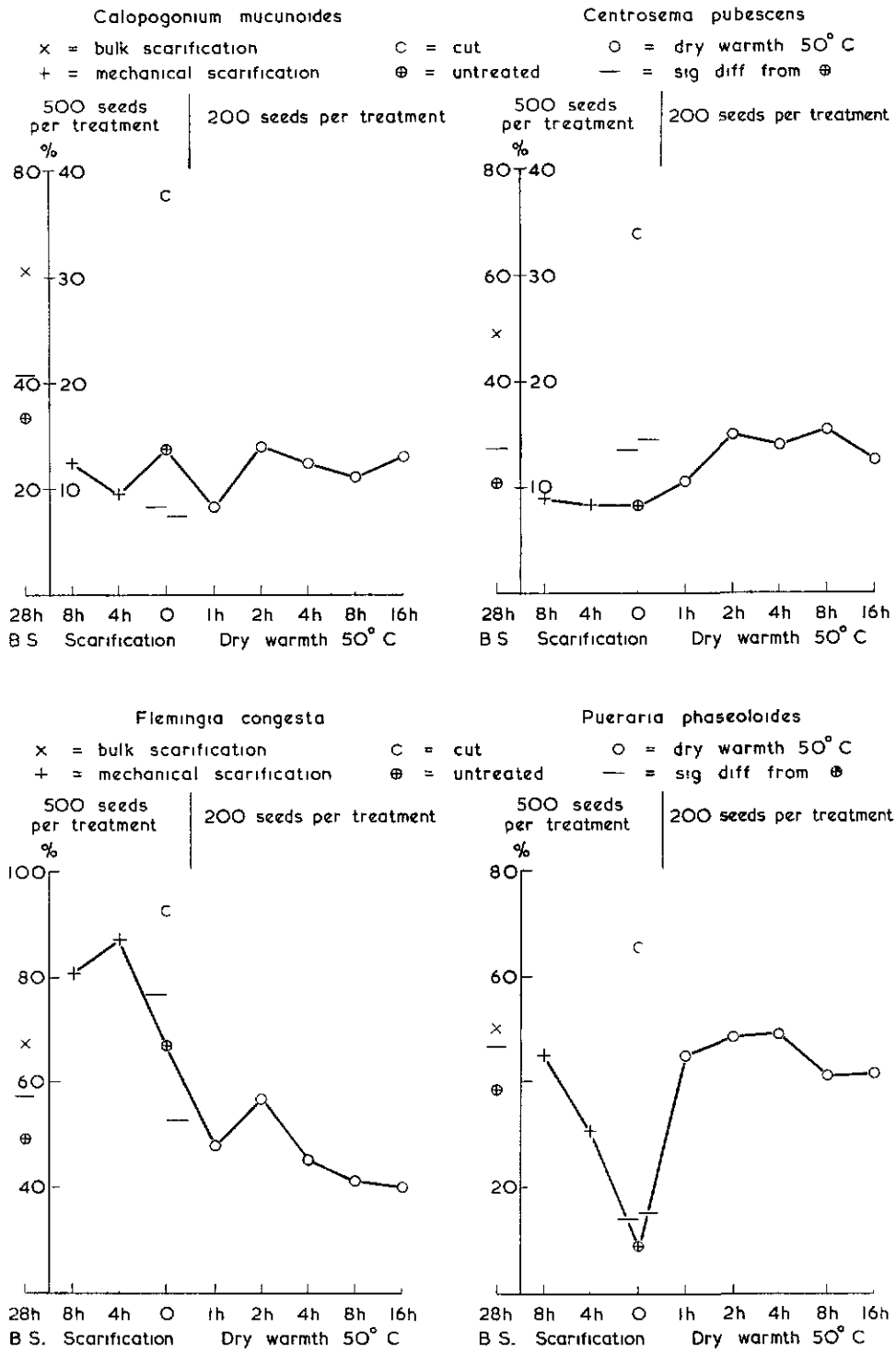

Figure 6. Effects on germination of mechanical scarification and dry warmth. The effects of 28 hours scarification of bulked seed (B.S.) is shown on the left of each graph.

2 x 300 seeds of each species were subjected to each pretreatment. 300 were set out to germinate without further treatment and 300 were cut also. The lengths of line indicate the percentage germination.

C = percentage germination obtained by cutting. Read percentage germination for both cut and uncut seed from O on scale.

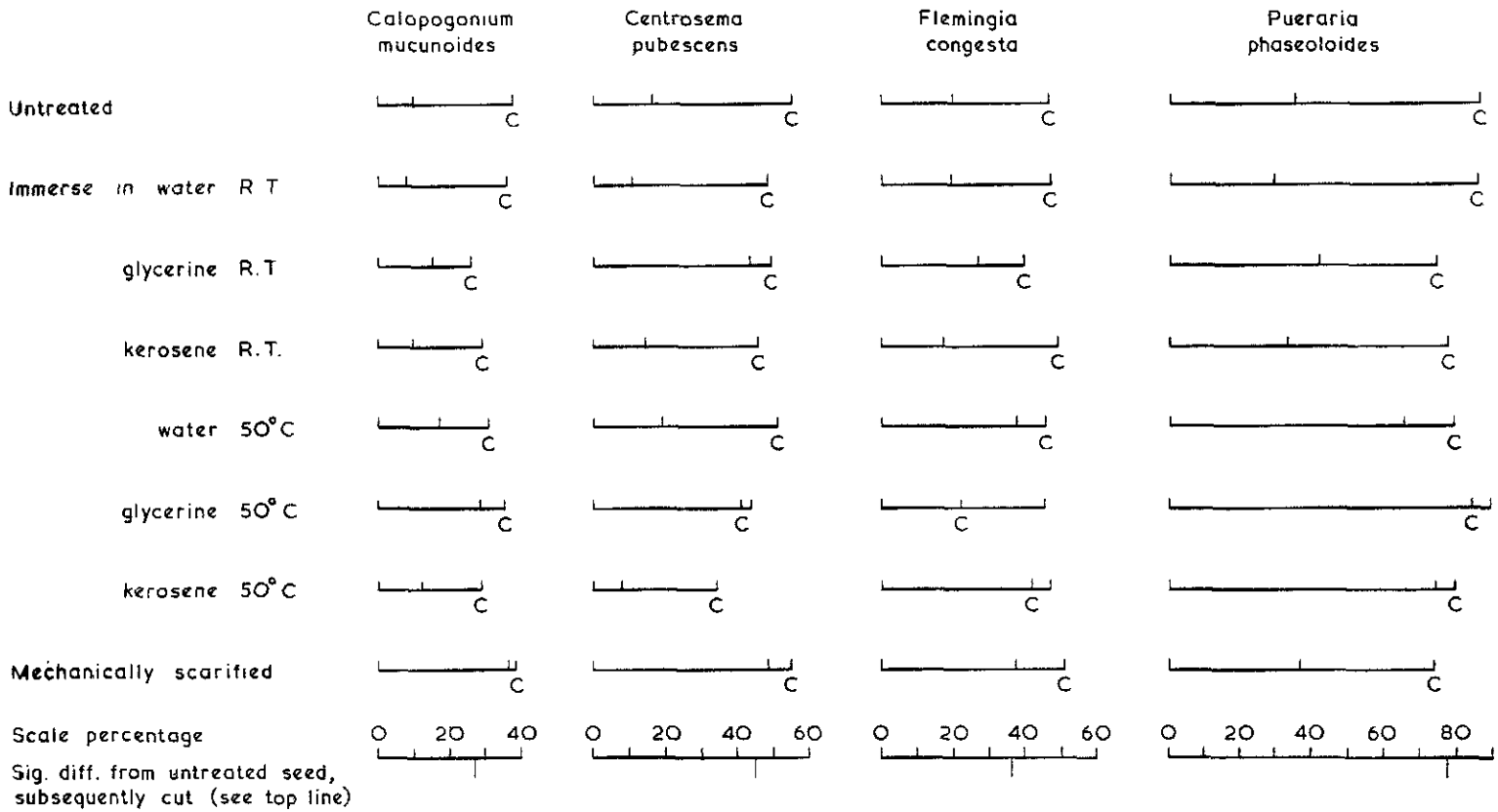

Figure 7. Percentage germination obtained by various treatments with or without subsequent cutting treatment.

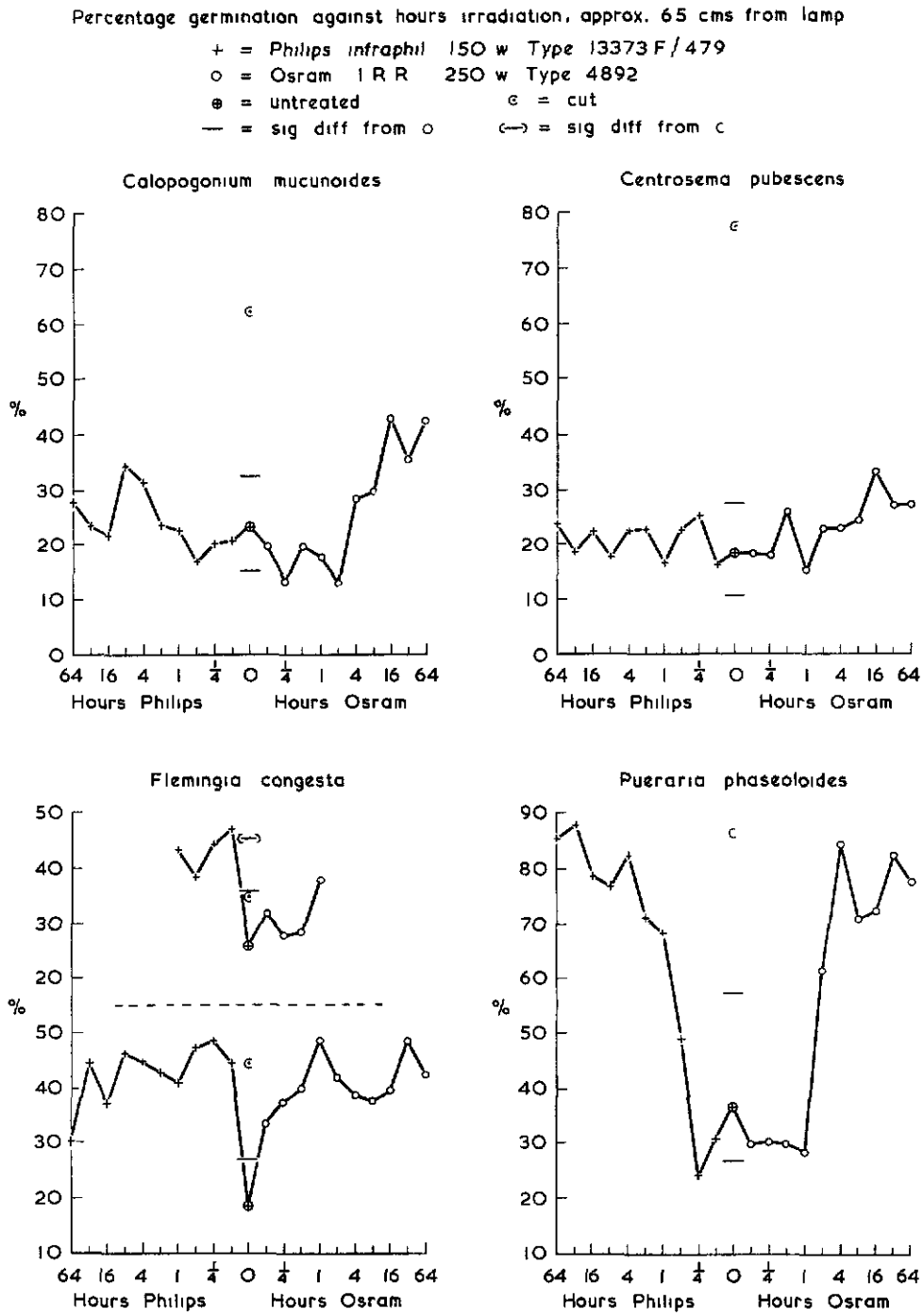

Figure 8. Effect of irradiation by infra-red lamps on germination of seeds. 300 seeds per sample.