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Original article

Growth-chamber trial on frost hardiness and field trial on flushing of sessile oak (*Quercus petraea* Liebl)

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Summary — The effects of late spring frost on 1-year-old seedlings of 10 European sessile oak provenances at different stages of development were simulated in growth chambers at temperatures ranging between –1.5 and –13 °C. For plants with: 1) swollen buds, 2) newly unfolded leaves or 3) young, fully developed leaves, the critical temperature for frost injuries was between –4 and –8 °C. Terminal buds, lammas shoots and secondary buds dehardened with delay during flushing. Therefore, the occurrence of frost damage to particular organs was dependent upon flushing stage at the time of exposure to frost. Following frost injury, most plants flushed by producing new leaves from secondary buds. Frost-hardiness variations were observed between the 10 provenances for plants at the same phenological stages.
Field studies conducted on 34 provenances revealed that those from southern and southeastern Europe flushed early. Consequently, they were more susceptible to late spring frosts than other provenances which flushed later.

Quercus petraea **/ frost hardiness / hardiness against late frost / flushing / growth-chamber / provenance / variation**

Résumé — Variabilité de la résistance au froid et du débourrement chez le chêne sessile. *L'effet des gelées tardives a été simulé en chambre de croissance sur des semis d'un an de chêne sessile appartenant à 10 provenances européennes. Les températures variant entre –1,5°C et –13°C ont été appliquées à différents stades de développement des semis. Les plants ayant soit des bourgeons gonflés, soit des jeunes feuilles repliées sur le bourgeon, soit des jeunes feuilles totalement allongées, sont sensibles aux dégâts de gelées à des températures variant entre –4 °C et –8 °C. Les bourgeons terminaux, les secondes pousses et les pousses axillaires se développent plus lentement durant le débourrement sous l'effet des basses températures. Les dégâts de gelée sur les différents organes dépendent de leur état de développement au moment de l'exposition au froid. Les plants endommagés par les gelées produisent de nouvelles pousses à partir de bourgeons axillaires. Des différences de réponse au froid ont été observées entre provenances au même stade de développement phénologique. Les observations faites dans les plantations comparatives sur 34 provenances ont montré que les origines sud et sud-est de l'Europe débourrent plus précocement. Celles-ci sont plus sensibles au gelées tardives que leurs homologues qui débourrent plus tardivement.*

Quercus petraea ***/ résistance au froid / résistance aux gelées tardives / chambre de croissance / provenance / variabilité***

INTRODUCTION

Previous studies on frost hardiness of broad-leaved species, especially sessile oak (*Quercus petraea* Liebl) are rather rare. Dengler (1944) reported frost injuries on oak cultures and forests in the cold winters of 1928–1929, 1937–1938 and 1941–1942. Larcher and Mair (1969) found that the cold resistance of *Quercus ilex* and other evergreen Mediterranean oak species increased with increasing age of trees. Harrasser (1969) studied the frost hardiness of *Acer pseudoplatanus* and found little difference between seedlings and adult trees. He described the frost resistance of different organs and tissues and concluded that frost hardiness is correlated with the natural distribution of this species. Studies on 38 *Quercus rubra* provenances showed that cold hardiness was greater than the local actual minimum temperatures (Flint, 1972) and was closely related to latitude of origin. Studies on the biochemical and physiological bases of cold resistance were reported by Santarius (1978) and Larcher (1981).

According to Larsen (1976), frost hardiness can be differentiated as hardiness against early frost (autumn), winter frost and late frost (spring). The objective of this study was to investigate the variability of budburst and tolerance to late spring frosts in European sessile oak provenances.

MATERIALS AND METHODS

Materials

This study was conducted on 34 provenances of *Q petraea* representing most of the area of its natural distribution (fig 1). An international collection in 1989, initiated by S Madson (Denmark), provided 18 provenances from 8 European countries and 1 from Turkey; an additional 16 samples were collected in Germany and Austria. Seed was sown in 1990 with 2 replications in the nursery of the Institute at Grosshansdorf.

Flushing

Flushing data were collected in the field from 100 plants of each of the 34 provenances on 6 dates from 11 April to 27 May 1991, according to the classification of Kleinschmit and Svolba (1979): stage 1: dormant buds; stage 2: swollen buds; stage 3: just unfolded leaves; stage 4: unfolded leaves; stage 5: developed leaves.

Frost hardiness

Frost hardiness against late frost was studied with 1-year-old plants of 10 provenances (fig 1). Plants at 3 phenological flushing stages (2, 3 and 5) were frost-treated in growth chambers. Late frosts were simulated at 11 different temperature regimens from −1.5 to −13 °C. The freezing protocol was as follows: + 6 °C for 4 h, then the chamber was cooled at 3 °C/h to the preset freezing temperature, which was maintained for 4 h and then the chambers were warmed at 3 °C/h until + 6 °C was reached. This temperature was maintained for a further 4 h. Following treatment, the plants were placed outside (April–May). Each growth chamber was loaded with 100 plants, 10–30/provenance. Frost damage to terminal buds, secondary buds and lammas shoots was scored as alive or dead (brown) 20 days after treatment.

RESULTS

Flushing

Flushing data were recorded for regions and countries: 8 provenances from North Germany (N-D), 10 from South Germany (S-D), 4 from France (F), 3 from Austria (A), 2 each from Belgium (B) and Denmark (DK) and 1 provenance each from Great Britain (GB), Poland (PL), Hungary (H) and Turkey (TR).

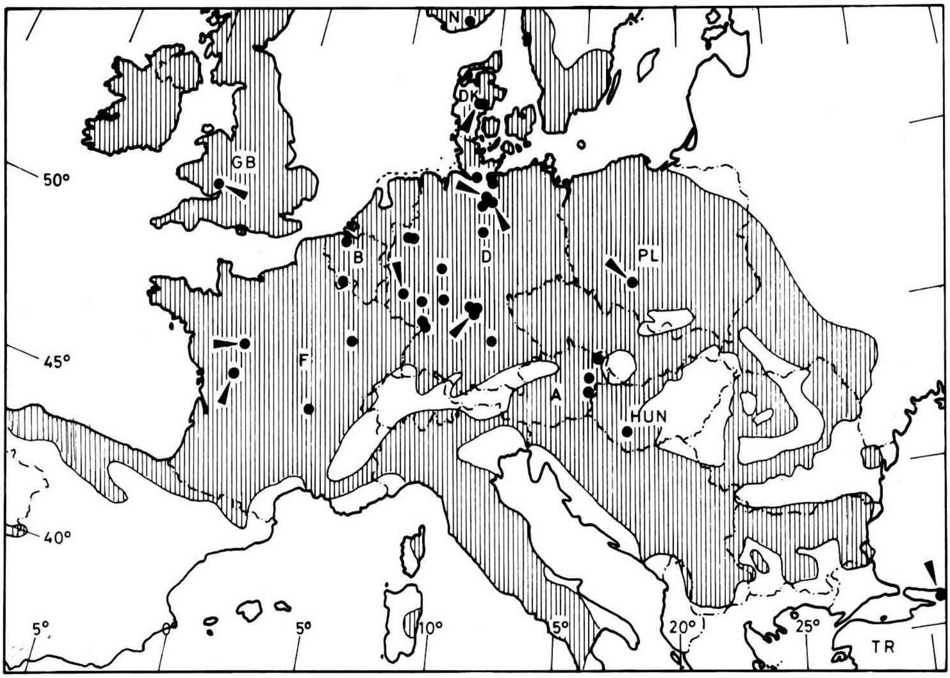

Fig 1. Natural range of *Quercus petraea* (IIII) and distribution of provenances examined for flushing (●) and late frost studies (—>). For abbreviations, see *Results*.

Results for 11 and 15 April 1991 are shown in figure 2. Subsequent assessments were influenced by a natural late frost which lasted from 18 April to 21 April with minimum temperatures of – 4°C and as a consequence, the provenance ranking for flushing development changed. Trees of provenances from Austria, Hungary and Turkey and a few from Belgium and France started flushing at the beginning of April, induced by a rather warm period in March. A period of 5 days with maximum temperatures of 28 °C at plant level, beginning on 10 April seemed to accelerate the development of all provenances; whereas, by 15 April more than 50% of plants from most provenances had reached at least flushing stage 2, those from Austria, Hungary, Turkey and France were at flushing stages 3 and 4. The development of the Austrian provenances was particularly advanced with 42 and 29% of plants at flushing stages 3 and 4, respectively. The natural late frost which followed this assessment was especially damaging to plants at stages 3 and 4 (fig 2), and the further development of such damaged plants was interrupted. The extent of frost damage sustained by provenances from countries considered in this study is illustrated in figure 3. Although some regional variation is evident, effects of latitude and longitude are apparent, with southern and eastern provenances being the most severely damaged.

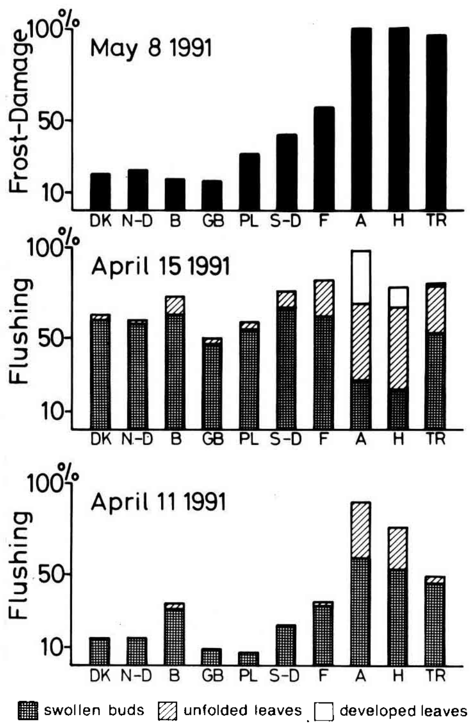

Fig 2. Mean % of oak seedlings flushed on 2 dates and mean % of frost-damaged plants from 34 European provenances compiled by country or region.

Frost hardiness

The results of the simulated late frosts in growth chambers are illustrated in figure 4. Data are the percent damage (averaged for all treated provenances) at 3 phenological flushing stages and 12 different frosting regimens, recorded separately for terminal buds, secondary buds and lammas shoots.

The first evidence of frost damage appeared on plants exposed to –3 to –4 °C with damage at these temperatures being more or less restricted to terminal buds. The gradient of the damage curve with decreasing temperature was similar for terminal buds irrespective of flushing stage (fig 4). This outcome contrasts with those for secondary buds and lammas shoots which became steeper as flushing advanced. At flushing stage 2, there were differences in sensitivity to frost between the different tissues examined (data not shown). Terminal buds were the least frost hardy, sustaining 25–75% damage at temperatures between –4 and –6 °C, lammas shoots were intermediate, being damaged at temperatures between –6 and –12 °C, while for secondary buds, damage (25%) began at about –12 °C. For plants with newly unfolded leaves (flushing stage 3), damage to terminal and secondary buds began at –2 to –3 °C. The slopes of the damage curves for terminal and secondary buds were similar to that plotted for stage 2, but for lammas shoots, the slope was steeper. By flushing stage 3, damage to all plant organs increased rapidly as temperatures declined between –4 and – 8 °C. At flushing stage 5, the slopes of damage curves were steeper than those for plants at earlier stages of development and terminal buds and lammas shoots sustained 100% damage at – 8 °C. While interprovenance variations of frost hardiness were found, the hardiness ranking was not consistent over the range of temperatures applied. However, in general, the French (Berce and Vouille Quincay) and Turkish provenances seemed the least frost hardy.

DISCUSSION

The basic parameters for the assessment of frost hardiness of forest tree species should be: 1) hardiness of organs and tissues at different stages of development; 2) variation of hardiness between provenances; and 3) variation of flushing.

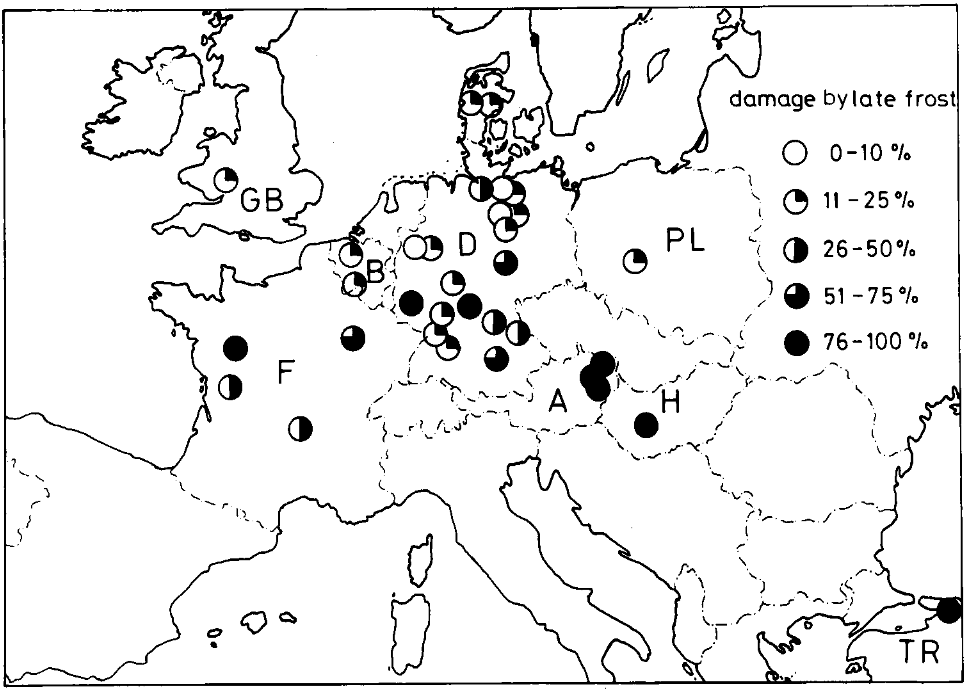

Fig 3. Variations in late frost damage to provenances from different regions from the natural range of sessile oak. For abbreviations, see *Results*.

Late frost studies of sessile oak provenances showed that terminal buds, lammas shoots and secondary buds dehardened and started flushing after a delay. During the early flushing stages, the variation of frost hardiness between these plant organs was wider than in later stages. Depending upon flushing stage, late frosts caused different injuries to plants. Normally, only terminal buds were damaged, but if late frosts were to occur each year or the frost were to affect plants at advanced flushing stages, consequences for further tree development and form must be expected. The question as to whether organs or tissues of sessile oak have different levels of frost resistance, as Harrasser (1969) described for *Acer pseudoplatanus*, cannot be answered as yet and requires further study. Frost hardiness of the studied provenances varied but for different frosting levels, ranks of provenances were not consistent. This inconsistency might be explained by genetic variation or perhaps because plant preconditioning was not always identical.

The comparison of late frost damage and flushing showed that the risk of damage increases with early budburst. Provenances from southern and southeastern Europe are particularly susceptible to late frost when transferred to regions where late frosts occur.

A regional variation in southern Germany was also found. According to Murray *et al* (1989), it is possible that these

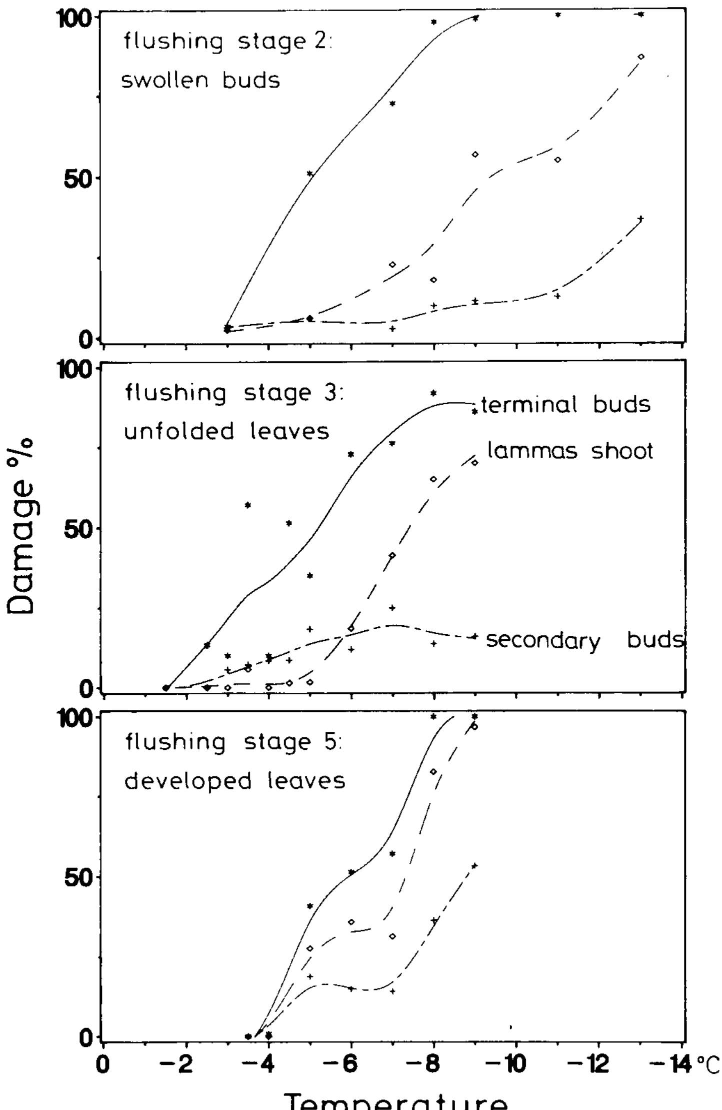

Fig 4. Late frost damage (in % of studied plants, 50–160) at different flushing stages (average for 10 provenances); for clarity, a cubic spline is fitted to each group of observed values.

provenances need a shorter heat sum for flushing, provided that their chilling requirement is satisfied. Whether early flushing provenances develop differently under changing preconditions or whether climate warming has an effect on frost hardiness, needs to answered by further studies.

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