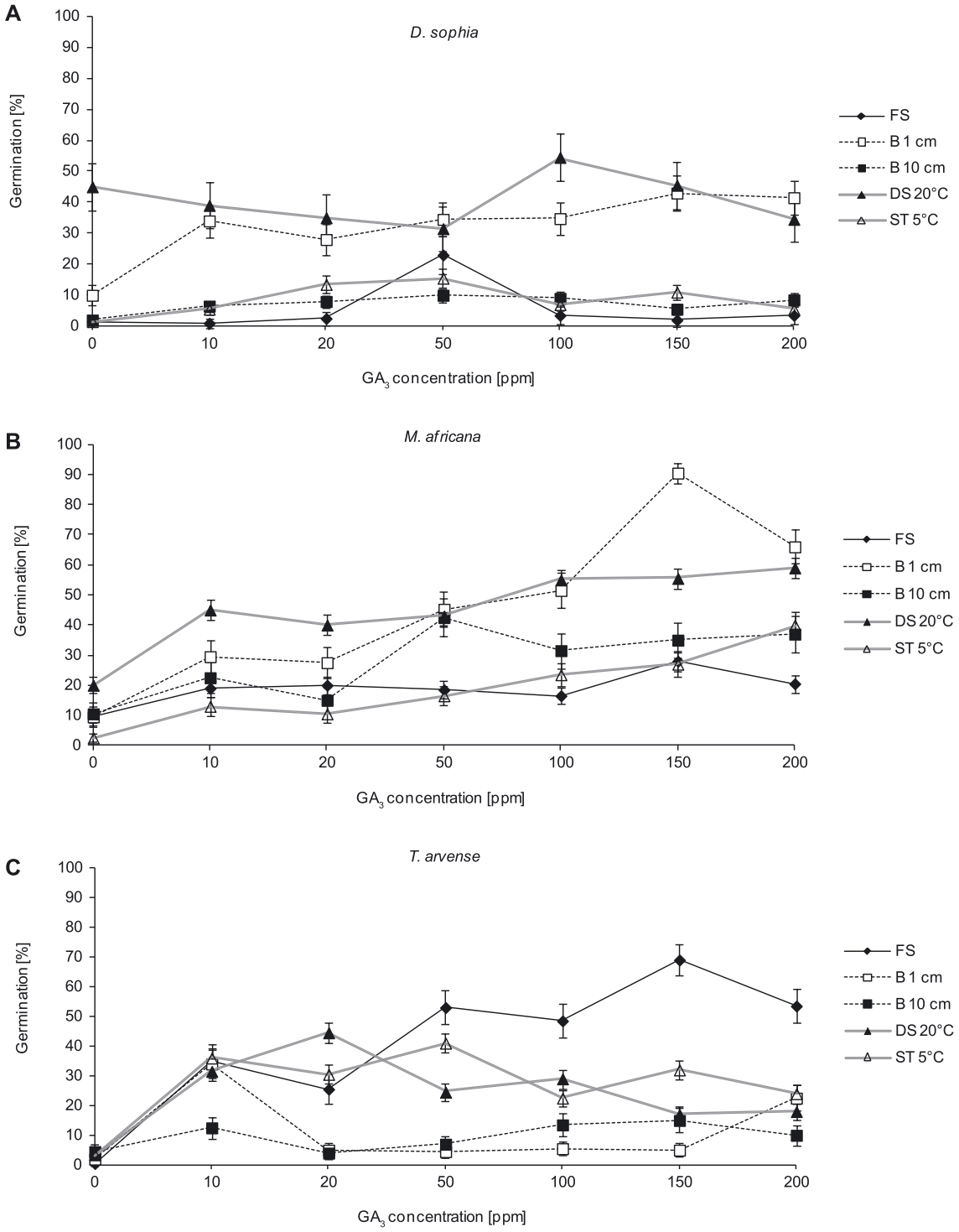

Fig. 4. Effect of GA_3 concentrations on germinability of seeds of *D. sophia*, *M. africana*, and *T. arvense* buried at 1 cm (B_1) and 10 cm (B_{10}) soil depths for 4 months, and dry seeds stored at 20°C (DS), and moist seeds stratified at 5°C (ST) for 6 months, and fresh seeds (FS). Vertical bars represent SEM

Table 4. Analysis of deviance for the effect of KNO_3 on seed germination of *D. sophia*, *M. africana*, and *T. arvense*

Source	Scaled deviance	df	F value	Pr > F
Species	247.7	2	242.12	0.0001
KNO_3	68.5	4	44.8	0.0001
Species × KNO_3	46.5	8	2.75	0.0146

Table 5. The effect of KNO_3 on seed germination of *D. sophia*, *M. africana*, and *T. arvense*

KNO_3 concentration [M]	Species		
	D. sophia	*M. africana*	*T. arvense*
	germination [%]		
0	1.5 (0.9)	9.5 (1.7)	0.5 (0.5)
0.0002	0.0 (0.0)	37.5 (3.0)	0.5 (0.5)
0.002	0.0 (0.0)	38.5 (2.2)	2.0 (1.4)
0.02	0.0 (0.0)	39.5 (10.4)	0.0 (0.0)
0.2	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)

Values in parenthesis represent SEM

Experiment 6. Scarification

Physical scarification caused a 22% increase in the germination percentage in *D. sophia* and 8% in *T. arvense* but had no effect on the germination of *M. africana* (data not shown). Chemical scarification with H_2SO_4 did not affect the germination in any of the species (data not shown).

Discussion

All three species showed different pattern of germinability depending on the duration of burial in the soil (Fig. 1). The differing patterns suggest there are differences in the level of seed dormancy among the species. Buried seeds of *D. sophia* at the depth of 10 cm showed increased germination after 30 days of burial in the soil, when air temperature in the preceding weeks was above 15°C (Table 1). Germination reached 55% in October with a subsequent reduction until the end of the experiment. Such reduction pattern indicate that there was a release of primary dormancy followed by induction. There was no consistent pattern to the changes in the germinability of *M. africana*. However, the germinability in the buried seeds of *T. arvense* started to increase after 90 days of burial. This increase suggests a deeper level of dormancy that needed a longer period of burial in the soil to release. The lower germination in seeds buried at 1 cm deep, might be due to high temperature fluctuation close the soil surface (Stoller and Wax 1973).

Dormancy level differences among species in Experiment 1 are consistence with results obtained from Experiment 2. An increase in germinability was observed after 90 days in *D. sophia* and after 120 days in *M. africana* and *T. arvense* seeds, dry stored at 20°C (Fig. 2). This shows that after-ripening of seeds during storage at ambient temperatures is critical for the germination of these species. Li *et al.* (2005) also observed dormancy release in *D. sophia* seeds after dry storage at room temperature. Best (1977) reported the release of dormancy in seeds of *D. sophia* in late autumn and early spring. Release of dormancy and increased germination in seeds of *T. arvense,* dry stored at 15°C and buried over winter, has also been reported (Andersson *et al.* 1997).

Stratification at 5°C did not cause a substantial increase in germinability in any of the species (Fig. 3). This implies, that seed dormancy combined with low temperatures in the habitat during the first autumn following dispersal, prevented seed germination of *D. sophia*, *T. arvense* and *M. africana*. Therefore, the low germination percentage of annual weeds in autumn at high latitudes, is attributed to decreasing temperatures which hamper the breaking of seed dormancy. Similar results were obtained by Taab and Andersson (2009) who studied dormancy in seeds of *Solanum nigrum* and recorded a negligible release of dormancy at 5°C. In contrast to our results, Milberg (1997) and Li *et al.* (2005) reported dormancy release in seeds of *D. sophia* and *T. arvense* stratified at 3°C. This contradiction could be due to the fluctuating effect or to the higher (25°C) temperature used for the germination test as compared with the constant temperature of 22°C used in our study.

The results showed that at certain concentrations, GA_3 may act as a stimulant (Fig. 4). For seeds of *D. sophia* buried 10 cm deep, for 4 months, GA_3 did not substantially increase germination (Fig. 4A). This might be due to a dormancy induction in the buried seeds after 4 months, as shown in Experiment 1 (Fig. 1). However, germination was higher for seeds buried 1 cm deep. This means that the dormancy had been reduced enough for seeds to respond to germination stimuli factors like GA_3. It is obvious, that seeds buried deep in the soil may stay dormant due to lack of enough oxygen for germination. The higher concentration of carbon dioxide prevents the germination process in deeply buried seeds. However, this might not be the case for seeds buried at shallower depths. It does not appear that GA_3 increases the germination of seeds dry-stored at 20°C for 6 months. As shown in Experiment 2 (Fig. 2), these seeds might have reached a maximum release of dormancy after this period, as well as maximum capacity to germinate (45%) at the present germination condition test. Thereafter, germination stimuli factors, like GA_3, have no further effect on stimulating germination. Germination response to GA_3 in *D. sophia* might be dormancy dependant.

For *M. africana*, seeds buried in the soil depth of 1 and 10 cm for 4 months, and seeds after dry storage at 20°C, there was a pronounced increase in germinability in response to GA_3 concentrations (Fig. 4B). Germination in

seeds dry stored at 20°C increased when the GA_3 concentration was 10 ppm, and there was little increase at higher concentrations. This treatment was found to best release dormancy in this species in Experiment 2 (Fig. 2). Germination reached its maximum at a GA_3 concentration of 50 (43%) and 150 ppm (90.5%) in seeds buried 10 and 1 cm, respectively. Maximum germination was 40% in seed stratified at 5°C for 6 months, at a GA_3 concentration of 200 ppm. The response to GA_3 was not notable in intact seeds. The germination response to GA_3 in *M. africana* might be associated with changes in the dormancy level with a variable response at higher concentrations.

All treated seeds of *T. arvense*, except seeds buried at a 10 cm soil depth for 4 months, showed increased germination (> 30%) at a GA_3 concentration of 10 ppm (Fig. 4C). This was followed by a considerable decrease in germination in seeds buried at a 1 cm soil depth at a GA_3 concentration of 20 ppm. There was also the tendency for a decreased germination at GA_3 concentrations above 20 ppm in dry stored seeds at 20°C, and at concentrations above 50 ppm in seeds stratified at 5°C. Surprisingly, intact seeds of *T. arvense*, representing a higher level of dormancy, showed an increase in germination with increased GA_3 concentrations. The maximum germination (69%) was achieved at a GA_3 concentration of 150 ppm. It is concluded, that a GA_3 concentration of more than 10 ppm might not be necessary to stimulate germination in treated seeds of *T. arvense*. The intricate interaction between stimulating, inhibiting, and limiting factors demonstrate that a series of requisites must be met for the seed to germinate. For instance, Derkx and Karssen (1993) reported that GA_3 sensitivity could be dependent on seed pretreatment conditions in *Arabidopsis thaliana*. They also showed an increased germination for GA_{4+7} concentrations with an increased effect in seeds with lower dormancy.

Potassium nitrate did not affect germination in seeds of *D. sophia* and *T. arvense*, whereas it increased germination in seeds of *M. africana*. Although nitrate may not influence the level of dormancy (Bouwmeester and Karssen 1993), it may remove constraints for seed germination (Benech-Arnold *et al.* 2000). For some seed populations, once the degree of dormancy is low, dormancy must be released by the effect of promoters such as nitrate for the germination process to proceed. Evidence for changes in sensitivity to the effect of nitrate, with changes in the degree of dormancy, was given by Hilhorst (1990), and Derkx and Karssen (1993). Germination of *S. nigrum* and *D. sophia* were also found to increase when potassium nitrate was applied (Roberts and Lockett 1978; Li *et al*. 2005). Germination in seeds of *M. africana* was higher (9.5%) in comparison with *D. sophia* and *T. arvense* (Table 5). The tested seeds of *M. africana* might have weaker levels of dormancy. These seeds responded to potassium nitrate for germination.

Physical scarification had little effect on promoting germination in *D. sophia* and *T. arvense*, and no effect on the germination of *M. africana* (data not shown). Chemical scarification with H_2SO_4 had no effect on the promotion of germination in any of the species (data not shown). Similar to our results, Moyo *et al.* (2009) reported that for *Sclerocarya birrea*, scarification with: H_2SO_4, boiling water, dry heat, and prolonged soaking of seeds did not improve germination. Von Teichman *et al.* (1986) showed that acid scarification was ineffective in enhancing seed germination of *S. birrea*. In experiments conducted by Ghadiri and Torshiz (2000), no significant increase occurred in germination when seeds of *Glycyrrhiza glabra* were chemically scarified with sulfuric acid for 15 min. We concluded, that type of dormancy in seeds of the studied species might be under the control of physiological phenomena rather than being a coat-imposed dormancy.

To sum up, the type of seed dormancy of the species is likely to be physiological and regulated by temperature. Buried seeds e.g. *D. sophia*, may go through a cycle of dormancy reduction and induction until seeds with a lower level of dormancy face the proper environmental conditions for germination, and finally germinate. This response can be used to predict the seedling emergence timing of the species in the field. Seed dormancy may be affected by GA_3 which may cause an increase in germinability depending on the pretreatment conditions and level of dormancy. Potassium nitrate increased germinability in seeds with reduced dormancy, as shown in *M. africana*. Therefore, applying KNO_3 may cause increased germinability of seeds in the soil seed bank. This could be used to stimulate seed germination and consequently, deplete the soil seed bank.

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