ABSTRACT
Six different levels of vigour of sorghum seeds from an identical lot were obtained through accelerated aging for various periods of time. Vigour was estimated according to yielding ability of the seed in the field. After 6 d of aging, seed invigoration, to the extent of a 20% increase in yield, was observed. However, this was followed by a gradual decrease in yield following aging of up to 48 d. All seed lots showed 88–92% germination or emergence capacity when tested in the laboratory, which correlates poorly with vigour. However, vigour correlated well with the rates of germination and root emergence when tested in the laboratory, as well as with emergence rate in the field.

INTRODUCTION
Agricultural productivity depends, to a large extent, on the quality of the seeds planted. Until now, seed quality has been measured in terms of purity and germination ability. The main disadvantage of such seed tests is that germination ability distinguishes only among growing seeds, abnormal seeds, and dead seeds. Therefore, the data obtained usually show the ratio among these three categories in a given seed lot, and do not reflect the quality or vigour of the viable seeds.

The definition of seed vigour was reviewed extensively by Heydecker (1972), Roberts (1972), and Perry (1976). Seed vigour has been measured by various parameters, of seed or seed lot characteristics. Not all investigators relate seed vigour to yield, but it seems obvious that vigour should represent the potential ability of the seed to yield the maximum plant product at the earliest time under variable environmental field conditions.

While seed vigour, in addition to germinability, is a known factor to farmers and scientists, the lack of definite criteria for judging it, and the wide range of crops studied, led to the accumulation of data with hardly any connection or even relation, between one factor and another.

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The present work represents an attempt to study the correlation between some biological phenomena and seed vigour in sorghum seeds from a uniform lot but at various aging stages.

MATERIALS AND METHODS

Seed source
All experiments were performed with certified seeds of sorghum cv. Hazera 610, obtained from a field previously sown with seed from an identical source. In the early experiments, hand-threshed and combine-threshed seeds were used and two seed-size lots were selected. As it was found that the largest seeds in a seed lot were undoubtedly superior to the small seeds, and that the hand-threshed seeds were less sensitive than the combine-threshed seeds, hand-threshed seeds of uniform size were used in all subsequent studies. After threshing, the seeds were air-dried to about 9.5% moisture content, and stored at 4°C and 35% r.h.

Accelerated aging treatment
To obtain seed samples of similar germinability but with different vigour levels, the seeds were submitted to an accelerated aging treatment. Basically, the method of Byrd and Delouche (1971) was used. Humidity and duration of treatment were carefully worked out so as not to impair the germinability of the seeds. Although the germinability of the seeds was not affected, it was assumed that physiological deterioration had already begun.

The accelerated aging method adopted consisted of having the seeds imbibe moisture up to 17% at 20°C, followed by additional storage in a closed container at 30°C. After various periods (of 0 to 48 d, termed herein 'time of aging'), seeds were air-dried down to 11% moisture and stored further, at 4°C and 35% r.h. Following accelerated aging treatments, seeds were tested for their germinability at various indicated time intervals. After 48 d, a decrease in germinability of 3–6% was observed, and the aging process was stopped.

Field emergence and yielding ability

Seeds aged for periods of 0, 6, 12, 24, 36, and 48 d were sown in the field as in common agricultural practice: 25 seeds m⁻¹ in nine randomized blocks, each 5 m long. Each plot consisted of two rows spaced 75 cm apart. Early field emergence occurred 6 d after sowing and emergence percentage was monitored daily until emergence had occurred. Twenty-four days after sowing, the plants were thinned out to five seedlings per metre row. The number of panicles was recorded at 67, 74, and 115 d after sowing; the number at 67 d was considered as the early yield.

Germination and germination rate

Germination was examined according to ISTA Regulations (1966). Germination rate was tested according to the same Regulations, but seedlings were evaluated after 3 d of incubation.

Rate of root emergence

Root emergence, defined as the rupture of the seed membrane by the root, was examined at 25°C after 24 h of incubation and at 15°C after 72 h.

RESULTS

The data in Table 1 show that for studies of seed vigour a seed lot uniform in size should be used. Moreover, the seeds may be compared after experimental treatment only when harvested under identical conditions. When hand-threshed seeds were compared with combine-threshed seeds for aging treatment stability, extremely great differences were found (see, for example, Fig. 4a). The physical, chemical, or biochemical differences between the hand- and combine-threshed seeds have not been investigated yet.

The effect of accelerated aging on seed vigour is demonstrated in Fig. 1. The assumption that seeds lost their vigour although the final germination percentage
**TABLE 1.** Effect of size of sorghum seeds (cv. H 610) on their percentage germination and emergence at various temperatures

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Seed size</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Large (31 g/1000 seeds)</td>
</tr>
<tr>
<td>Germination (20–30 °C)</td>
<td>85</td>
</tr>
<tr>
<td>Emergence (20–30 °C after 10 d)</td>
<td>86</td>
</tr>
<tr>
<td>Weight, green matter (g/100 plants)</td>
<td>9.1</td>
</tr>
<tr>
<td>Weight, dry matter (g/100 plants)</td>
<td>0.9</td>
</tr>
<tr>
<td>Normal germination (at 18 °C after 18 d)</td>
<td>76</td>
</tr>
<tr>
<td>Normal emergence (at 18 °C after 18 d)</td>
<td>82</td>
</tr>
<tr>
<td>Normal germination (at 15 °C after 20 d)</td>
<td>64</td>
</tr>
</tbody>
</table>

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**FIG. 1.** The effect of accelerated aging time on early harvest yield (Δ) and field emergence (●) of sorghum. Sorghum seeds were treated for accelerated aging. Samples were taken at various indicated time intervals and then sown in the field; rate of emergence and the early number of panicles were monitored as described in Materials and Methods. For early harvest yield, $r = 0.89$; for field emergence, $r = 0.87$.

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...did not drop significantly was verified in field experiments. There was a decline in the early yield (Fig. 1); it occurred unexpectedly, after an invigoration on the sixth day of accelerated aging. The meaning of this early invigoration is discussed in the accompanying paper (Perl, Luria, and Gelmond, 1978). The field emergence curve in the present investigation follows that of the yield profile (see Fig. 1), and thus the latter was used as a criterion of vigour and simplified the tests of vigour.
There was practically no difference between the variously aged seed lots in final germination, whereas the germination rate followed the curve obtained from the early yield of panicles (Fig. 2).

![Graph showing germination rate and capacity over time]

**Fig. 2.** The effect of accelerated aging time on the germination rate and germination capacity of sorghum seeds. Sorghum seeds were treated for accelerated aging as described under Fig. 1; they were examined for rate of germination (●) and for germination capacity (○) as described in Materials and Methods.

The rate of root emergence shown in Fig. 3 seems to be linear between 22 and 32 h. The aged seeds (48 d) showed a slight linear increase during this time interval, followed by a sharp increase up to about 46 h. Therefore, root emergence rate is measured after 24 h at 25 °C. The effect of aging on seed vigour is presented by various vigour characteristics in Fig. 4. The effect of temperature on root emergence (Fig. 4A) indicates that the rate of emergence declines independent of the seed aging treatment. Surprisingly, as the temperature of imbibition was lowered, the effect of the aging treatment became more apparent in the root emergence phenomenon: At 25 °C an increase appeared at 6 d of aging; at 18 °C the increase disappeared but no decrease could be noted at the early stage of aging; seed imbibition at 15 °C resulted in an immediate decrease in root emergence, directly correlated with time of aging (compare Fig. 4A and B). Seedling growth is often used as a measurement of seed vigour. As shown in Fig. 4C this parameter
FIG. 1. The root emergence of sorghum seeds as a function of imbibition time. Aged (○) and non-aged (●) sorghum seeds were imbibed in Petri dishes at 25 °C. The root emergence was monitored at indicated intervals as described in Materials and Methods.

may be correlated with time of aging, but only at large variations in seed vigour. Similarly, the sensitivity to temperature stress conditions (cold test) may be used to differentiate between seed lots with large vigour differences but not for those which vary in minor degrees of vigour (Fig. 4D).

DISCUSSION
Although the concept of vigour is often discussed and is well known from farmers' experience, it is rarely understood. The necessity of a uniform seed lot with identical agricultural background and seed size for the study of seed vigour has been demonstrated. To obtain various degrees of vigour, hand-threshed and uniform-sized seeds were aged artificially for various periods of time. We are aware that the aging process in these experiments may differ from that which occurs naturally. However, the treatment was such that it could represent natural storage conditions, under which seeds may lose their original vigour. It should be emphasized that all the aged seeds which were examined maintained their original viability and therefore none was ‘killed.’ In our opinion, this is the first prerequisite in studying seed vigour.
The vigour of sorghum seeds measured by various laboratory characteristics, following different levels of accelerated aging. 

A. Imbibition time: 45 h (•); 73 h (○); 168 h (△). All 18 °C, hand-threshed. 
B. (•) Hand-threshed, 24 h imbibition; 25 °C; (○) combine-threshed, 24 h imbibition, 25 °C; (△) hand-threshed, 72 h imbibition, 15 °C. 
C. Seedling length × germination percentage after 4 d of imbibition. 
D. Cold test: imbibed for 5 d at 5 °C, then transferred to 30 °C for 24 h (●) or 168 h (○); all hand-threshed seeds.

A comparison of seed lots with various germination capacities, as often made (e.g. Abdul-Baki and Anderson, 1973; Ries and Everson, 1973; Yaklich and Abdul-Baki, 1975; Ries, Ayers, Wert, and Everson, 1976), may lead to a statistical study of the relative effect of viable and non-viable seeds rather than differences in seed vigour. Another prerequisite for study of seed vigour is that any activity for testing vigour should be correlated, wherever possible, with the yield under similar
conditions (optimal or suboptimal), which is the actual expression of the seed's potential or vigour.

The data presented in this paper show that, by the aging process of hand-threshed uniform-sized seeds, six sorghum seed lots were obtained which differed in their early yield performance although their original germination ability was practically unchanged (see also Welch and Smith, 1973). Early in the aging process (6 d), an invigoration process was observed which was followed by a constant loss in vigour up to 48 h. Apparently, such invigoration may occur in spite of the fact that some activities may already be damaged. By biological tests, the early yield or seed vigour could be measured and predicted according to the rate of root emergence, of germination, or field emergence (Maguire, 1962; Williams and Hanson, 1974). It may thus be concluded that seed vigour means a high rate of the overall biological activities of the seed, resulting in a high yield performance.

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LITERATURE CITED
