Asian Journal of Plant Sciences

ISSN 1682-3974

science alert

ANSInet
an open access publisher
http://ansinet.com

Asian Journal of Plant Sciences 2 (13): 983-992, 2003
ISSN 1682-3974

Effects of Time of Harvest at Different Moisture Contents on Seed Fresh Weight, Dry Weight, Quality (Viability and Vigour) and Food Reserves of Peas (*Pisum sativum* L.).

A.B. Siddique and [1]D. Wright
Genetic Resources and Seed Division, Bangladesh Jute Research Institute
Manik Mia Avenue, Dhaka-1207, Bangladesh
[1]School of Agricultural and Forest Sciences, University of Wales, Bangor, Gwynedd, United Kingdom

Abstract: Harvesting seed crops of peas (*Pisum sativum* L.) at different moisture content provided evidence that seed vigour appeared after physiological maturity and continued until some time after physiological maturity and then declined as harvesting was delayed. It was observed that seed vigour was highest when seed moisture content was lowest. The results of the present study provided contrasting evidence against Harrington's hypothesis about seed longevity and deterioration as maximum seed quality was not attained at physiological maturity and this did not start deteriorating after physiological maturity.

Key words: Peas, moisture content, seed, maturity, viability, vigour

Introduction

Maximum seed viability and seed vigour may be achieved if seeds are harvested at the correct stage of maturity. If harvesting is delayed seed quality may decline due to adverse environmental conditions such as high temperature, high humidity, rainfall, over drying, attacks by diseases, pests or damage by birds and animals (Copeland and McDonald, 1995). A seed crop should be harvested soon after achieving the maximum seed quality. Physiological maturity (PM), mass maturity (MM) and harvest maturity (HM) are three important terms which are closely related to seed quality. Physiological maturity was probably first defined by Shaw and Loomis (1950) as the stage in seed development when the seed reaches its maximum dry seed weight and yield. This same stage was also termed relative maturity by Aldrich (1943), morphological maturity by Anderson (1955) and more recently mass maturity by Ellis and Pieta-Filho (1992). Since the moisture content of the seed is often too great for mechanical harvesting and threshing at PM, further desiccation must occur before direct harvesting is possible. Harvest maturity is defined as the first time the seed moisture declines to a harvestable level in those crops harvested as dry seeds and/or fruits (TeKrony and Egli, 1997).

It is widely accepted that PM represents the end of the seed filling period and the maximum yield for any crop harvested as dry seed. The lingering question is, does PM also represent maximum seed quality for planting purposes? Harrington (1972) proposed that developing seeds attain maximum quality (vigour) at PM, after which deterioration starts and seed germination and vigour decline, with the rate of decline dependent upon the storage environment. This hypothesis was supported by research for more than two decades by many physiologists for many crop species such as Chen *et al.* (1972), Maguire (1977), Delouche (1980), Powell *et al.* (1984) and Ellis *et al.* (1987). More recently, Ellis and associates have concluded that maximum seed quality (vigour) does not occur until some time after PM (Pieta-Filho and Ellis, 1991a,b; Rao *et al.*, 1991; Ellis and Pieta-Filho, 1992; Zanakis *et al.*, 1994). They concluded that maturing seeds of soybean and corn do not attain maximum ability to survive storage (potential longevity) until sometime after PM.

Hence they now refer to this stage as mass maturity, rather than physiological maturity (Ellis and Pieta-Filho, 1992). In such case seed quality (vigour) may continue to increase even after the seeds have reached maximum seed dry weight (mass maturity). They achieve physiological maturity and maximum seed vigour at some later stage, after maximum seed dry weight (mass maturity) but before harvest maturity, the stage at which a grain crop is harvestable i.e. usually 10-15 % seed moisture content (fresh weight basis). Ferguson (1993) found that in different cultivars of combining pea maximum seed quality was attained 14 to 19 days after the stage of maximum seed dry weight. In his study seed quality did not decline before harvest maturity. He concluded that Harrington's hypothesis may be rejected in the case of combining pea. TeKrony and Egli (1997) suggested that the relationship between the occurrence of maximum seed dry weight and maximum seed vigour may depend on the experimental techniques used in the investigations, particularly how

the seeds are harvested and dried. This paper studies the effects of time of harvest on the optimum seed moisture content to maximize seed germination and vigour and the relationship between seed maturation and seed quality i.e. germination, vigour and storage reserves in seeds of peas.

Materials and Methods

Site description: The experiments were conducted in two years, utilizing seed crops grown in pots in 1998 and a field in 1999. In 1998 the experimental crops were grown in large pots, outside and in an area sheltered from excessive wind at the Henfaes Research Centre of the University of Wales, Bangor, United Kingdom. In 1999 the experimental crops were grown in a field of the same research centre.

Experimental details: In 1998 seeds were harvested at 7 days intervals, starting at 30 days after first flowering on 18.08.98 when the seeds had a moisture content of 77% and continued up to 86 days after first flowering, when the seeds had a moisture content of 18% (fresh weight basis) respectively. In 1999 seeds were harvested starting at 23 days after first flowering on 02.08.99 and continued up to 27, 31, 37, 41, 44, 52, 60, 69, 75 and 79 days after first flowering, when the seeds had a moisture content of 77.1, 72.4, 66.2, 59.5, 54.4, 46.4, 28.7, 23.8, 20.0, 24.5, 29.8 and 47.6% (fresh weight basis) respectively. There were four plots, each 30m x 1.2m, comprising 10 rows 12 cm apart. Seed samples from each plot were kept separate during harvesting, drying and testing and were considered as replicates.

General agronomic management practices: In 1998 Clay loam top soil was collected from an agricultural field, sieved and used to fill sixty four pots (holding capacity of 70 litres), 44 cm diameter and 65 cm deep. The plants were sown on 03.06.1998 and were managed according to normal agronomic management practices. Twenty four seeds were sown in each pot. When the seeds emerged the seedlings were thinned to twelve plants per pot, which is equivalent to 79 plants per m^2. Fertilizer (50 kg P_2O_5 ha^{-1} and 50 kg K_2O ha^{-1}) was applied prior to sowing and mixed by hand. Watering was done manually as and when necessary. The weeds were removed by hand. In 1999 the trial was first sown on 29.04.99 in the field. Fertilizer (50 kg P_2O_5 ha^{-1} and 50 kg K_2O ha^{-1}) was applied prior to drilling and the crops were grown in rainfed condition. The weeds were also removed by hand as and when necessary and were managed according to normal agronomic management practices. No nitrogenous fertilizer was applied. The pea variety was Baccara.

Harvesting, sampling procedures and determination of seed fresh weight, dry weight and moisture content: When the first flower opened first flowering date was recorded. In 1998 the first harvest was taken 30 days after first flowering and then further harvests were made at 7 days intervals until two weeks after harvest maturity (HM). Harvest maturity was defined as when the seed moisture content was <20% (fresh weight basis) and the pods were completely brown. At each harvest except the one at harvest maturity all plants from one pot (randomly selected) were harvested, the pods removed and the seeds shelled out. To determine the seed fresh weight, dry weight and moisture content, a random sample of 20 seeds was drawn from the seed bulk and fresh weight recorded. To determine the dry weight and moisture content, seeds were dried in an oven at 105°C for 48 h. Moisture content was calculated (fresh weight basis) following the formula as described by ISTA (1976a,b).

$$\text{Moisture content \%} = \frac{\text{Fresh weight} - \text{dry weight}}{\text{Fresh weight}}$$

At maturity on 28.09.98 and 72 days after first flowering, all the plants of all 15 remaining pots were harvested. After each harvest all pods were collected by hand. The remaining seeds were then dried at 40°C until they reached around 12% moisture content. After this drying the seeds were placed in paper bags and stored at room temperature in the laboratory to allow for dormancy breaking, prior to the determination of germination percentage. From the seed bulk, four separate samples were taken and used as replicates in the seed testing procedures.

In 1999 the first harvest was made 23 days after flowering and the final one 79 days after flowering. At each harvest 20 plants were randomly selected and harvested from each of the four replicates of the field plots by hand. All the pods were collected. In the initial harvests the seeds were very small and soft and there were possibilities of causing mechanical injury and damage to the harvested seeds. Hence, in all harvests the pods were allowed to dry for 3 days without threshing in an unheated glasshouse and the seeds were threshed out later. After threshing the seeds were air dried in the same unheated glasshouse and when the seeds had reached a moisture content of around 12% they were then placed in paper bags and stored in the laboratory at room temperature to allow for dormancy breaking. To determine seed fresh weight, dry weight and moisture content a random sample of 50 seeds was taken straight away after harvest from each replicate of the bulk seeds and dried at 105°C for 48 h. The procedures

followed to calculate moisture content percentage were identical to those followed in 1998. In 1999, the seeds harvested from the four separate replicate plots of the field experiment were taken as the four replicates used in the determination of fresh weight, dry weight and moisture content and in the post harvest quality tests.

Testing seed quality: Seed quality testing started on 05.01.99 and 24.11.99, approximately two and a half and two months after the final harvests in 1998 and 1999 respectively. Before starting seed quality measurements seed dormancy was tested by determining the germination percentage of a small sample of seeds. To determine the effects of time of harvest on seed quality, a germination test at 20°C was performed on the seeds harvested in 1998 and 1999. In addition, an emergence test was performed on the seed harvested in 1999.

Procedures for emergence test: The emergence test took 21 days to complete, from sowing to taking the final recordings. It used 50 seeds per replicate of each harvest and was conducted in soil in pots in an unheated glasshouse at the same time as the germination tests. The mean soil temperature during this period was 8.26°C±0.59. The mean maximum daily air temperature recorded throughout this period was 13.5°C and the mean minimum daily air temperature recorded was 4.1°C. The first count of emergence was tried to record at 7 days but no seeds emerged within this time. A seed was considered emerged when its first two leaves protruded out about 2.5 cm above the soil. Final emergence was recorded 21 days after sowing. No further emergence occurred after this time.

Chemical analysis: In 1999 the chemical composition of seeds (fat, protein, water soluble carbohydrate and starch percentage) from 5 selected harvests (23, 31, 44, 60 and 79 days after first flowering) using all 4 replicates of each treatment was also determined following procedures described by MAFF (1986).

Statistical analysis: All data were analysed by the Analysis of Variance (ANOVA) method, using Minitab statistical package version -12. Significance levels of the variance ratio (F) are shown in the tables by *** for 0.1% probability levels. Non significant differences are donated by NS. Tests of differences between means were made at the 5% probability level when a significant F value was obtained for sampling time effect. Different treatment means were compared by calculating a Least Significance Difference (LSD) as follows:

LSD = √((2EMS)/n) x t (0.05), df.
Where EMS = error mean square; from analysis of variance table
n = number of replications (6);
t = (0.05)
df = value from the t distribution table at 5% probability level and appropriate error degrees of freedom (df).

An analysis of Basic Statistics was performed on the data to calculate standard error of the means.

Results

Fig. 1 and 2 show the effects of time of harvest on seed fresh weight, dry weight, moisture content and germination of pea seeds grown in pots in 1998. Fig. 3, 4 and 5 shows the effect of time of harvest on seed fresh weight, dry weight, moisture content, germination and emergence percentage of pea seeds grown in the field in 1999.

Seed fresh weight: In 1998, by the time measurements started seed fresh weight was declining. Fig. 1 shows that in 1998 from pot experiments seeds attained maximum fresh weight before 58 days after first flowering and 42% moisture content. In 1999 from field experiments seeds attained maximum fresh weight at 41 days after first flowering and at around 52% moisture content (Fig. 3). In both year seed fresh weight declined and at very late harvests it increased slightly in 1998 and markedly in 1999 due to uptake of water from rain.

Seed dry weight: In 1998 maximum seed dry weight was achieved before 58 days after first flowering and in 1999 maximum seed dry weight was achieved at 42 days after first flowering. At this time in 1998 seed had around 42% moisture content and in 1999 seed had around 52% moisture content (Fig. 1 and 3). At later harvests there was no increase in dry weight, though moisture content decreased. Seed dry weight remained constant after 58 and 42 days after first flowering in 1998 and 1999 respectively. In 1998 the increase in seed dry weight from 58 days to 86 days after first flowering was not significant but in 1999 the increase in seed dry weight from 37 days to 42 days was significant.

Seed moisture content: Fig. 1 and 3 show the effects of time of harvest on the moisture content of pea seeds. As harvest time was delayed moisture percentage of seeds decreased in both years. In 1998 this decrease was large up to 58 days after first flowering and relatively small from 65 to 74 days after first flowering. Moisture percentage

Table 1: Effect of time of harvest on starch, protein, water soluble carbohydrate (WSC) and fat percentage of pea seeds grown in the field in 1999

DAFF	Starch %	Protein %	WSC %	Fat %
23	29.2	25.8	3.4	1.2
31	32.3	21.8	3.5	1.5
44	45.2	21.3	3.8	1.5
60	47.3	23.1	3.8	1.4
79	40.1	22.8	5.0	1.4

(DAFF = days after first flowering)

	SED	LSD
Starch	3.58	7.64***
Protein	0.67	1.43***
Water soluble carbohydrate	0.14	0.29***
Fat	0.17	NS

increased slightly at 79 days after first flowering. This was the last harvest and it was later than the time of harvest maturity. In 1999 the decrease in moisture content was large up to 44 days after first flowering and relatively small from 52 to 60 days after first flowering. Moisture percentage increased from 69 to 79 days after first flowering, due to uptake of water from rain.

Germination percentage: Figures 2 and 4 shows the effect of time of harvest on the germination percentage of pea seeds in 1998 and 1999. As harvest time delayed germination percentage increased in both years. The effects of time of harvest on increasing germination percentage was statistically significant ($p<0.001$). In 1998 at the first harvest seeds had not yet acquired the ability to germinate. At later harvests germination percentage reached a peak of 96% at 65 days after first flowering. This was maintained until 72 days after first flowering and then significantly declined. In 1999 germination increased up to 52 days after first flowering, reached a peak of 97% and was similar up to 69 days after first flowering and then significantly decreased at later harvests. However, the increase in germination between 30 days and 52 days after first flowering was not significant.

Emergence percentage: An emergence test was performed in 1999 only. It started on 24.11.99 in cold and wet soil. At early harvests, although seeds had acquired the ability to germinate, emergence was very low. As harvest was delayed emergence percentage increased (Fig. 5). Emergence percentage was highest at 60 days after first flowering and at 20% seed moisture content and then it decreased significantly. The emergence percentage was highest when seed moisture content (MC) was lowest at 60 days after first flowering. As this test was performed in cold and wet soil, so seeds attained maximum quality (vigour) in relation to sowing purposes when moisture content was 20% at the time of harvest. This was 18 days after maximum seed dry weight had been achieved.

Seed nutrient percentages: The values for starch, protein, water soluble carbohydrate and fat percentages in seeds

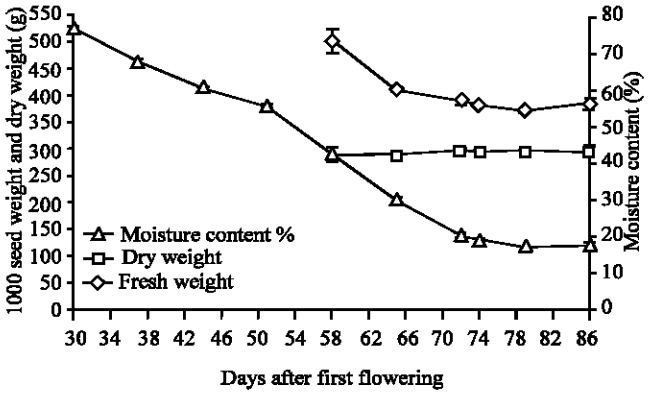

Fig. 1: Effects of time of harvest on fresh weight, dry weight and moisture content of pea seeds grown in pots in 1998 (vertical bars are ± SE of the means)

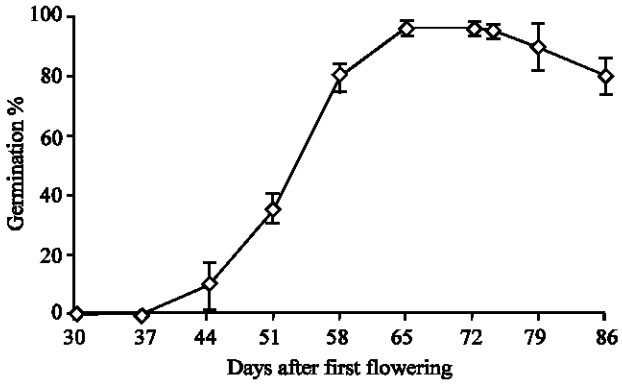

Fig. 2: Effects of time of harvest on germination % of pea seeds grown in pots in 1998 (vertical bars are ± SE of the means)

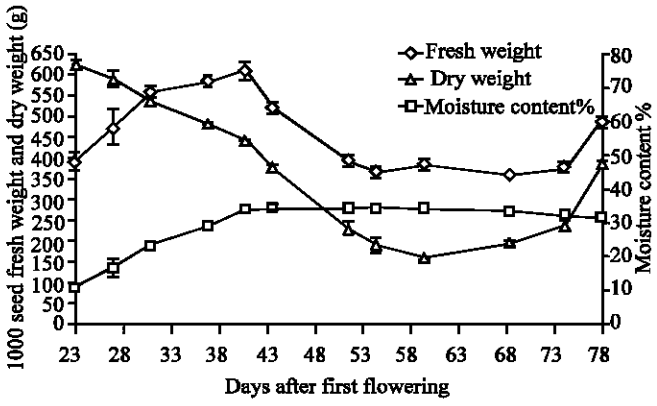

Fig. 3: Effects of time of harvest on fresh weight, dry weight and moisture content of pea seeds grown in the field in 1999 (vertical bars are ± SE of the means)

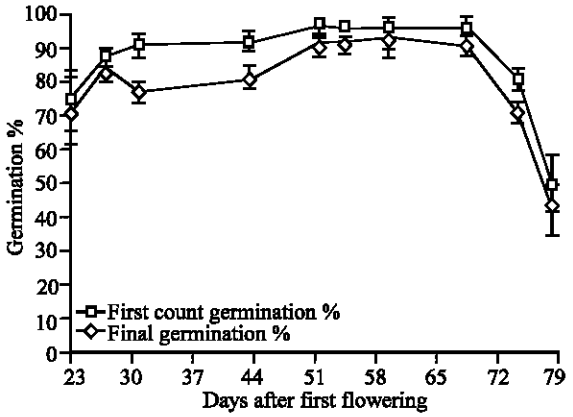

Fig. 4: Effects of time of harvest on first count and standard germination percentage of pea seeds grown in a field in 1999 (vertical bars are ± SE of the means)

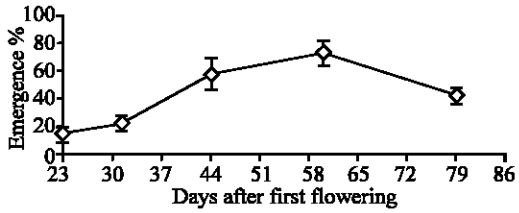

Fig. 5: Effects of time of harvest on emergence percentage of pea seeds grown in a field in 1999 (vertical bars are ± SE of the means)

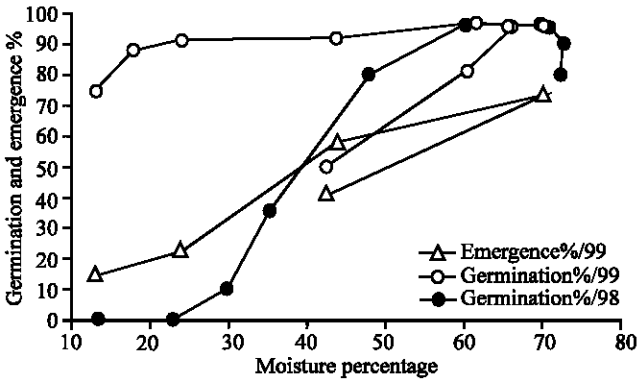

Fig. 6: Effects of moisture content on seed germination and emergence percentage of pea seeds

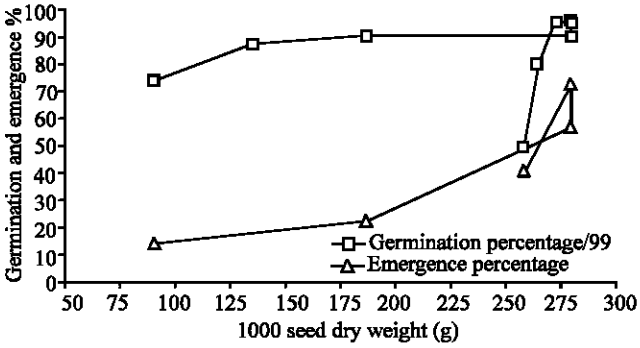

Fig. 7: Effects of seed dry weight on seed germination and emergence percentage of pea seeds

are given in Table 1. As time of harvest delayed starch percentage increased. Starch percentage increased up to 60 days after flowering and decreased thereafter. As harvest was delayed protein percentage decreased. The highest protein percentage was found at 23 days after flowering and thereafter it declined. As time of harvest delayed water soluble carbohydrate increased. This increase was small from 23 to 60 days after flowering but relatively higher from 60 to 79 days after flowering. Fat percentage was very small and similar at all the harvests.

Discussion

It is well known fact that harvesting a seed crop at the proper time is very important for seed quality. Seeds must be harvested when they achieve the maximum vigour. Plant reproductive development begins with formation of the flower bud and progresses through anthesis, fruit development and accumulation of storage materials in the seed. Reproductive development ends at physiological maturity, when the seed reaches its maximum dry weight (TeKrony and Egli, 1997). Harrington (1972) reported that maximum seed quality was attained at physiological maturity, after which deterioration started and seed germination and vigour declined. This hypothesis was supported by research for two decades (TeKrony and Egli, 1997). More recently some scientists concluded that maximum seed quality does not occur until some time after physiological maturity (Pieta-Filho and Ellis, 1991a,b; Rao *et al*., 1991; Ellis and Pieta-Filho, 1992; Zanakis *et al*., 1994). In the early stages of seed development the seed moisture content is high. Seeds harvested too early, at high seed moisture content, tend to deteriorate more quickly and also suffer greater mechanical damage during processing due to their soft seed coat. Seeds harvested too late become over dry. The ideal harvesting time is before loss of mature seeds from shattering, lodging and mechanical seed damage (Copeland and McDonald, 1995). Therefore it is necessary to identify the stage at which seeds achieve the maximum seed quality with safe storability. In these studies for peas maximum seed quality (vigour) occurred some time after physiological maturity. These results are in agreement with the results of other workers (Pieta-Filho and Ellis, 1991a,b; Rao *et al*., 1991; Ellis and Pieta-Filho, 1992; Demir and Ellis, 1992a,b; Ellis and Hong, 1994; Zanakis *et al*., 1994). The contrasting conclusions from these investigations and those of

Harrington and associates for those species harvested as dry seeds may be due to: (1) the methods used for harvesting, drying and handling of high moisture and/or immature seeds, (2) whether seed harvests were made on an individual seed or plant community basis and (3) the methods used to measure seed vigour. In the early stages of seed development the seed moisture content was very high, ranging from around 77%. It is not possible to measure seed vigour of such high moisture seeds (TeKrony and Egli, 1997). Thus, the seeds must be dried before testing. In these experiments in 1998 seeds were threshed straight away after harvest and dried at 40°C for a week. In 1999 seeds were dried in an unheated glasshouse for three days attached to or enclosed in the detached pods and then threshed and again dried in the same glasshouse until the seed attain 12% moisture content. These contrasting methods of processing and drying had a marked effect on seed viability, which is discussed below.

Effects of time of harvest on seed fresh weight, dry weight and moisture content of seeds: Flowering was initiated 44 and 48 days after sowing in 1998 and 1999 respectively. The effects of time of harvesting on 1000 seed fresh weight, dry weight and moisture content are shown in Fig. 1 and 3 in 1998 and 1999 respectively. Harvesting the crop early would have resulted in yield loss due to high seed moisture content, high percentage of immature seeds and low 1000 seed weight. An observation showed that as the harvesting was delayed, more seeds were filled and consequently, average seed weight increased. All these findings are in agreement with the findings of Nimje and Gandhi (1994). These changes brought about rapid increases in 1000 seed dry weight in both species. In these studies maximum seed dry weight was found after less than 58 and 42 days after first flowering in 1998 and 1999 respectively. Thereafter it remained constant.

The moisture content of the seed decreased with the delay in the date of harvesting. It was found to be minimum at 79 and 60 DAFF in 1998 and 1999 respectively. Thereafter it increased slightly in 1998 and increased markedly in 1999. This increase was due to rain at very later harvests. There was a gradual increase in seed dry weight with reduction of seed moisture content. In 1998 and 1999 after attaining around 42 and 52% seed moisture content, pea seeds did not show any increase in dry weight, even when their moisture content decreased to 17 and 20% in both years. In these studies mass maturity stage occurred when pea seeds attained around 42 and 52% moisture content in 1998 and 1999 respectively. There was no further increase in dry weight for further loss of seed moisture content. An observation showed that at mass maturity the pods of peas turned completely brown. The increase in dry weight of the seeds towards maturity reflects the accumulation of non structural carbohydrates, reducing sugars and fibre, relative to seed moisture content which showed a sharp fall (Ketsa and Poopattarangk, 1991).

The results of the seed quality (viability and vigour) tests showed that peas achieved the maximum seed dry weight at around 42 and 52% seed moisture content in 1998 and 1999 respectively. In 1998 peas achieved maximum viability after mass maturity and this was maintained until after some time of mass maturity and then declined. In 1999 seeds attained maximum seed quality (vigour) relatively later, at 20% seed moisture content. Afterwards, seed quality declined as the harvesting was delayed. In this study in 1999 the highest seed vigour was observed 19 days after physiological maturity and when the pods in peas were completely brown. Farmers may be able to decide about mass maturity by pods colour.

Effects of time of harvest on seed germination: Seeds of most species are capable of germinating long before physiological maturity (Harrington, 1959; Hill and Watkin, 1975; Pegler, 1976; Rasyad *et al*., 1990; Galau *et al*., 1991). Ferguson (1993) reported that partially filled fresh seeds of combining pea could germinate immediately after removal from the mother plant under normal laboratory germination test conditions. Maximum seed germination can only be obtained if the seeds are allowed to dry slowly as they mature (Adams *et al*., 1983). Germination tests for seed quality showed that in 1998 the germination of seed from some initial harvests was zero. It may be that seeds are unable to withstand enhanced drying following removal from the parent plant until they have undergone some slow dehydration whilst still on the plant (Matthews, 1973). In 1999 the germination of seed from initial harvests was considerably higher even though the moisture content was similar. The seeds of the 1999 experiments may have continued maturation for a short time after harvest while attached to the fruit, which may partially explain the higher seed quality at this earlier stage of development. Comparing germination of oven dried seeds at 40°C (in 1998) and air dried seeds at the similar developmental stage (in 1999), it is interesting to note that allowing seed to air dry enhanced the germination capacity mainly of immature seeds to its maximum value. Adams *et al*. (1983) also suggested that by allowing the immature seed to desiccate slowly, maturation events were permitted to occur after immature seed was removed from the parent plant. In 1998 seeds dried quickly at 40°C and immature seeds removed from the pods showed severe cracking of the testa, wrinkling of the seeds and much lower germination than for seeds air dried slowly for some time in the pods in 1999. Zanakis

et al. (1994) reported that enforced desiccation of naked seeds was fatal to most immature, green soybean seeds. Thus, it seems possible that the rapid drying of naked seeds may explain the consistently lower germination in the early harvests in 1998. In 1998 seeds harvested too early (37 days after first flowering) germination was zero, when the seed had very high moisture content and low dry weight. Pea seeds showed maximum germination (96%) at 65 DAFF, when the seed attained around 30% moisture content. This high percentage of germination continued until 74 DAFF, when their moisture content was around 19% and thereafter declined. Here, it should be noted that pea seed attained maximum dry weight before 58 DAFF and at that time their moisture content was around 42% and germination was <80%.

In 1999 seeds harvested very early (at 23 DAFF) germination was high (around 75%), when seed had very high moisture content and very low dry weight. Pea seed showed highest germination (97%) at 52 DAFF and around 29% moisture content. This high percentage of germination was maintained until 69 DAFF, when moisture content had fallen to around 24% and thereafter it declined. It should be noted that in 1999 seeds attained maximum seed dry weight before 42 DAFF and at that time moisture content was around 52% and germination was close to 90%. It can be concluded that as an early harvested seed crop is more sensitive to post harvest management technique i.e. seed drying, so if it is necessary to harvest crops early they should not be threshed straight away, but should be allowed to dry slowly in the pods for a few days and then threshed. Seed crops should be normally harvested some time after physiological maturity for optimum germination. As germination and vigour declined in delayed harvesting.

Effects of time of harvest on seedling emergence: An emergence test was performed in 1999 only. The results showed that, seed harvested early (at 23 DAFF and at around 77% seed moisture content) emergence in soil was very low compared to laboratory germination percentage. Emergence increased as harvesting was delayed until after some time after physiological maturity. It increased up to 60 DAFF and at around 20% seed moisture content. However, emergence was significantly decreased at the last harvest. Low emergence in very mature seeds has been attributed may be to changes in cotyledons. Matthews (1971) reported that the mortality in soil shown by viable seeds may be linked with changes in the ability of the cotyledons to withstand enhanced drying because the condition of the cotyledons has been found to be responsible for low soil emergence of otherwise viable seeds. Bain and Mercer (1966) reported that as the pea cotyledon matured there was a gradual breakdown of the endoplasmic reticulum. They suggested that the endoplasmic reticulum acts as a temporary storage system for soluble reserves, especially sucrose, during early germination. The rapid loss of moisture in immature seeds may disturb the slow organized breakdown of a membrane system within the cells of the cotyledons during ripening and result in a disruption in the subsequent re-development of the membranes during early germination (Matthews and Whitbread, 1968). The possible causes of low emergence at later harvests may also be associated with adverse weather conditions, such as excessive rainfall, drought, wind and shattering losses of better seeds (Austin, 1972; Delouche, 1980). Low emergence at early harvests may be associated with imbibition damage. Some circumstantial evidence suggests that early harvesting and drying may produce seeds that are viable but predisposed to fungal infection and consequently mortality in soil and show low emergence. However, the highest emergence was achieved some time after physiological maturity (when the seeds attained maximum seed dry weight) and thereafter it declined.

Relationship of germination and emergence percentage with moisture content of pea seeds: As moisture content decreased with delayed harvesting germination percentage of pea seeds in both years (1998 and 1999) increased and reached a peak when moisture content was lowest and then decreased again with increasing moisture content. The reasons for the phenomena of decreasing moisture content with increasing germination at the early stages of seed development and increasing moisture content with decreasing germination at the delayed harvesting stages are not the same. At very early stages of seed development pea seeds had high water content and the pods and seeds were green in colour, bearing chlorophyll and capable of photosynthesis to prepare food reserves. The cause of losing water from the seed at this stage may be the fact that seeds preserve solid/concentrated food reserves instead of water. The cause of increasing moisture content at later stages of harvest is uptake of water from rain. This uptake of water at the later harvests deteriorated seed quality by decreasing germination of the seeds in both years but not at the same ratio of decreasing moisture content with increasing germination and emergence at early harvests. The relationship between moisture content and germination was not the same in both years. Therefore moisture content percentage cannot be used as a guide to germination, although it should be noted that different techniques were used in the two years.

Effects of time of harvest on seed nutrient percentages: Seed nutrient percentages were highly influenced by time of harvesting. It was found that the main food reserve in peas was starch (47.3%). Starch, fat, protein and water soluble carbohydrate were detected. In peas it was found in the order starch > protein > water soluble carbohydrate > fat. In peas starch percentage was highly increased by the delay in harvesting time up to 60 DAFF and showed a declining trend thereafter. The protein content was highest at early harvest (23 DAFF) and slightly decreased as harvesting was delayed. The decline in protein percentage towards maturity is in agreement with the observation reported for green peas (Gritton *et al*., 1975). Nitsch (1958) suggested that this decline is possibly due to the utilization of protein for pod growth. Furedi (1970) reported that the ratio of crude protein to total dry matter decreased in the developing pea seed and attributed this to the accumulation of starch in the seed. According to Smith (1973), RNA and starch synthesis in *Pisum arvense* cease before maturation but protein synthesis continued until the seeds are ripe. Chitre *et al*. (1950) found that protein content of peas increased with maturity, but percent protein decreased. All these findings are in agreement with the present study. Analysis of water soluble carbohydrate and fat showed that the levels of these were very low. As harvesting was delayed water soluble carbohydrate slightly increased.

The synthesis of starch begins immediately after flowering and the seed contains relatively little starch in the first 31 days of development. After this, comes another period of four weeks during which the formation of starch takes place. During the last two weeks till harvest maturity starch content changed little. The highest starch formation occurs during the period between physiological maturity and harvest maturity. In this experiment it was observed that it takes nearly 60 days after first flowering for completion of starch synthesis in peas.

Therefore, it can be concluded that in these studies seed viability appeared before mass maturity and was maintained until some time after mass maturity and declined thereafter. Maximum seed vigour appeared some time after mass maturity. These findings are in agreement with the findings of other workers (TeKrony *et al*., 1980; Kameswara *et al*., 1991; Ellis and Pieta-filho, 1992; Ellis *et al*., 1993; Ferguson, 1993) and in disagreement with Harrington (1972) and associates who supported him over the two decades. It is concluded that the hypothesis of Harrington is not valid in peas as demonstrated also in several other crops. The results of these experiments also show that the use of the term physiological maturity to describe the end of the seed filling period (Shaw and Loomis, 1950) is potentially misleading with regard to the physiological status of pea seeds. Consequently, it supports the recommendation that mass maturity (Ellis and Pieta-Filho, 1992) is a more appropriate term to denote the end of the seed filling period.

There are probably numerous factors in seed production that can influence the emergence ability of seed. However the results of this work suggest that the immature seeds of the early harvests are not able to withstand enhanced drying without death or damage. Harvesting and drying before this ability could be the cause of reduced viability and viable seeds with low soil emergence potential.

Acknowledgements

We thank Mrs Ll G Hughes of the University of Wales for her expert technical assistance and the World Bank for providing a studentship to A B Siddique.

References

Adams, C.A., M.C. Fjerstad and R.W. Rinne, 1983. Characteristics of soybean seed maturation: Necessity for slow dehydration. Crop Sci., 23: 265-267.

Aldrich, S.R., 1943. Maturity measurements in corn and an indication that grain development continues after premature cuttings. J. Am. Soc. Agron., 35: 667-680.

Anderson, S.R., 1955. Development of pods and seeds of birdsfoot trefoil, *Lotus corniculatus* L., as related to maturity and seed yields. Agron. J., 47: 483-487.

Austin, R.B., 1972. Effects of environment before harvesting on viability. In Viability of Seeds, (Ed. E. H. Roberts), Syracuse University Press, Syracuse, New York, pp: 114-149.

Bain, J.M. and F.V. Mercer, 1966. Subcellular organization of the developing cotyledons of *Pisum sativum* L. Australian J. Biol. Sci., 19: 49-67.

Chen, C.C., C.H. andrews, C.C. Baskin and J.C. Delouche, 1972. Influence of quality of seed on growth, development and productivity of some horticultural crops. Proceedings of the International Seed Testing Association, 37: 923-939.

Chitre, R.G., J.N. Williams and C.A. Elvehjem, 1950. Nutritive value of canned foods. J. Nutrition, 42: 207.

Copeland, L.O. and M.B. McDonald, 1995. Seed viability testing. In Principles of Seed Science and Technology (3rd Ed.), Chapman and Hall, New York, pp: 111-126.

Delouche, J.C., 1980. Environmental effects on seed development and seed quality. Hort. Sci., 15: 775-780.

Demir, I. and R.H. Ellis, 1992a. Development of pepper (*Capsicum annum*) seed quality. Annals of Applied Biol., 121: 385-389.

Demir, I. and R.H. Ellis, 1992b. Changes in seed quality during seed development and maturation in tomato. Seed Sci. Res., 2: 81-87.

Ellis, R.H. and T.D. Hong, 1994. Desication tolerance and potential longevity of developing seeds of rice (*Oryza sativa* L.) Annals of Bot., 73: 501-506.

Ellis, R.H. and C. Pieta-Filho, 1992. The development of seed quality in spring and winter cultivars of barley and wheet. Seed Sci. Res., 2: 9-15.

Ellis, R.H., I. Demir, C. Pieta-Filho and F. Corinean, 1993. Changes in seed quality during seed development in contrasting crops. Proceedings of Fourth International Workshop on Seeds: Basic and Applied Aspects of Seed Biol., pp: 897-904.

Ellis, R.H., T.D. Hong and E.H. Roberts, 1987. The development of desiccation tolerance and maximum seed quality during seed maturation in six grain legumes. Annals of Bot., 59: 23-29.

Ferguson, A.J., 1993. The agronomic significance of seed quality in combining peas (*Pisum sativum* L.). PhD Thesis, University of Aberdeen.

Furedi, J., 1970. Changes in the protein content when crossing pea varieties. In Protein Growth by Plant Breeding, (Ed. A.P. Balint), Akademiai Kiado, Budapest, Hungary.

Galau, A.J., K.S. Jackson and D.W. Hughes, 1991. The controls of late dicotyledons embryogenesis and early germination. Physiol. Planetarium, 81: 280-288.

Gritton, E.T., Y. Pomeranz and G.S. Robbins, 1975. Protein content and amino acid composition of developing peas. J. Food Sci., 40: 584-586.

Harrington, J.F., 1959. Effect of fruit maturity and harvesting methods on germination of musk melon seed. Proceedings of the American Soc. Hort. Sci., 73: 422-436.

Harrington, J.F., 1972. Seed storage and longevity. In Seed Biology, Vol. 3, (Ed. T.T. Kozlowski), New York: Academic Press, pp: 145-245.

Hill, M.J. and B.B. Watkin, 1975. Seed production studies on perennial ryegrass timothy and prairie grass. II. Changes in physiological components during seed development and time and method of harvesting for maximum yield. J. Br. Grassland Soc., 30: 131-140.

ISTA, 1976a. International Rules for Seed Testing. Rules 1976. Seed Sci. and Technol., 4: 3-49.

ISTA, 1976b. International Rules for Seed Testing. Annexes 1976. Seed Sci. and Technol., 4: 51-177.

Kameswara, R.N., R.S. Appa, M.H. Mengesh and R.H. Ellis, 1991. Longevity of pearl millet (*Pennisetum glacum* L) seeds harvested at different stages of maturity. Annals of Applied Biol., 119: 97-103.

Ketsa, S. and S. Poopattarangk, 1991. Growth, physico-chemical changes and harvest indices of small edible-podded peas (*Pisum sativum* L. Var. macrocarpon). Tropical Agriculture, 68: 274-278.

MAFF., 1986. In Reference book 427 The Analysis of Agricultural Materials a manual of the Analytical Methods used by the Agricultural Development and Advisory Services, Ministry of Agriculture, Fisheries and Food, UK (3rd Ed.). Her Majesty's Stationary Office London.

Maguire, J.D., 1977. Seed quality and germination. In The Physiology and Biochemistry of Seed Dormancy and Germination, (Ed. Khan A.A.), North Holland Publishing Company, Amsterdam, pp: 219-235

Matthews, S., 1971. A study of seed lots of peas (*Pisum sativum* L.) differing in predisposition to pre-emergence mortality in soil. Annals of Applied Biol., 68: 177-183.

Matthews, S., 1973. The effect of time of harvest on the viability and per-emergence mortality in soil of pea (*Pisum sativum* L.) seeds. Annals of Applied Biol., 73: 211-219.

Matthews, S. and R. Whitbread, 1968. Factors influencing pre-emergence mortality in peas. I. An association between seed exudates and the incidence of pre-emergence mortality in wrinkle seeded peas. Plant Pathol., 17: 11-17.

Nimje, P.M. and A.P. Gandhi, 1994. Effect of stage of harvesting and nitrogen levels on yield and oil quality of linseed (*Linum usitatissimum* L). J. Oilseeds Res., 11: 141-151.

Nitsch, J.P., 1958. The physiology of food growth. Annual Rev. Plant Physiol., 4: 199-236.

Pegler, R.A.D., 1976. Harvest ripeness in grass seed crops. J. Br. Grassland Soc., 31: 7-13.

Pieta-Filho, C. and R.H. Ellis, 1991a. The development of seed quality in spring barley in four environments. I. Germination and longevity. Seed Sci. Res., 1: 163-177.

Pieta-Filho, C. and R.H. Ellis, 1991b. The development of seed quality in spring barley in four environments. II. Field emergence and seedling size. Seed Sci. Res., 1: 179-185.

Powell, A.A., R. Don, R. Haigh, G. Phillips, J.H.B. Tonkin and O.E. Wheaton, 1984. Assessment of repeatability of controlled deterioration vigour test both within and between laboratories. Seed Sci. and Technol., 12: 421-427.

Rao, N.K., S.A. Rao, M.H. Mengesha and R.H. Ellis, 1991. Longivity of pearl millet seeds harvested at different stages of maturity. Annals of Applied Biol., 119: 97-103.

Rasyad, A., D.A. Van-Sanford and D.M. TeKrony, 1990. Changes in seed viability and vigour during wheat seed maturation. Seed Sci. and Technol., 18: 269-267.

Shaw, R.H. and W.E. Loomis, 1950. Bases for the prediction of corn yields. Plant Physiol., 25: 225-244.

Smith, D.L., 1973. Nucleic acid, protein and starch synthesis in developing cotyledons of *Pisum arvense*. Annals of Bot., 37: 795.

TeKrony, D.M. and D.B. Egli, 1997. Accumulation of seed vigour during development and maturation. In Basic and Applied Aspects of Seed Biol., (Eds. R.H. Ellis, M. Black, A.J. Murdock and Hong T.D.), Kulwer Academic, London, pp: 369-384.

TeKrony, D.M., D.B. Egli and J. Balles, 1980. The effect of the field production environment on soybean. In Seed Production (Ed. P.D. Hebblethwaite). Butterworths, London-Boston, pp: 403-425.

Zanakis, G.N., R.H. Ellis and R.J. Summerfield, 1994. A comparison of changes in vigour among three genotypes of soybean (*Glycine max*) during seed development and maturation in three temperature regimes. Experimental Agriculture, 30: 157-170.