AgRISTARS

EW-U1-04115
JSC-17157

A Joint Program for
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May 1981

ENVIRONMENTAL FACTORS DURING SEED DEVELOPMENT AND THEIR INFLUENCE ON PRE-HARVEST SPROUTING IN WHEAT

E82-10114

NASA CR-161015

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(E82-10114) ENVIRONMENTAL FACTORS DURING SEED DEVELOPMENT AND THEIR INFLUENCE ON PRE-HARVEST SPROUTING IN WHEAT (Department of Agriculture) 22 p HC A02/MF A01 CSCL 02C N82-22589 Unclas G3/43 00114

U.S. Department of Agriculture
1050 Bay Area Boulevard
Houston, Texas 77058

Lyndon B. Johnson Space Center
Houston, Texas 77058

1. Report No. JSC-17157; EW-U1-04115	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle

Environmental Factors During Seed Development and Their Influence on Pre-Harvest Sprouting In Wheat

5. Report Date

May 1981

6. Performing Organization Code

7. Author(s)

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8. Performing Organization Report No.

9. Performing Organization Name and Address

USDA/SEA-AR
Pullman, Washington

10. Work Unit No.

11. Contract or Grant No.

T-956 9G

12. Sponsoring Agency Name and Address

National Aeronautics and Space Administration
AgRISTARS/Early Warning/Crop Condition Assessment
1050 Bay Area Blvd.
Houston, Texas 77058

13. Type of Report and Period Covered

Literature Review

14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

Pre-harvest sprouting in wheat is a problem associated with all wheat producing areas of the world which have summer rainfall prior to harvest. The majority of the damage occurs in areas where soft white wheat are grown, i.e., Australia, northern Europe, and the United States. The areas affected in the United States include the Pacific Northwest and several states bordering Canada. Other areas in the world where preharvest sprouting may be a problem include parts of Chile, Argentina, Brazil, South Africa, Rhodesia, Kenya, Saskatchewan and Manitoba in Canada, and eastern New Zealand.

When summer rains precede harvest, a wheat seed can imbide water and germinate in the spike prior to harvest, which is detrimental to both the grower and the processor. This germination in the spike can cause reduction both in yield and test weight. Yield losses in excess of 10% are not unusual.

A number of physiological, biochemical, morphological, and environmental factors have been suggested to have an input into preharvest sprouting, but this review will mainly discuss the environmental effects of pre-harvest sprouting in wheat. Where physiological, biochemical, or morphological changes occur within the wheat seed due to environmental changes, these factors will also be discussed.

17. Key Words (Suggested by Author(s))

Pre-harvest sprouting
Wheat loss
Head sprouting
Lose in dormancy

18. Distribution Statement

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	19	

*For sale by the National Technical Information Service, Springfield, Virginia 22161

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AND

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Introduction:

Pre-harvest sprouting in wheat is a problem associated with all wheat producing areas of the world which have summer rainfall prior to harvest. The majority of the damage occurs in area where soft white wheats are grown, i.e., Australia, northern Europe, and the United States. The areas affected in the United States include the Pacific Northwest and several states bordering Canada. Other areas in the world where preharvest sprouting may be a problem include parts of Chile, Argentina, Brazil, South Africa, Rhodesia, Kenya, Saskatchewan and Manitoba in Canada, and eastern New Zealand.

When summer rains precede harvest, a wheat seed can imbibe water and germinate in the spike prior to harvest, which is detrimental to both the grower and the processor. This germination in the spike can cause reduction both in yield and test weight. Yield losses occur during the thrashing process when the coleptiles and the radicles together with the light, depleted grains are thrown over the cleaning units of the combines. Belderok (1968) estimated that yield reductions of 10% were not to be unusual.

Test weight (specific gravity or packing ratio of the grain) values will also be reduced due to pre-harvest sprouting. This lowering of the test weight will result in a dockage to the farmer at the local elevator. The test weight is lowered because the seed swells when it takes up water, but when it dries, the seed will not be reduced to its original size, thus resulting in the lowering of test weight.

Over 1.8 million tons of wheat were rendered unsuitable for bread making in northern New South Wales in November, 1967 (Moss, et al, 1972). Derera (1980) estimated that 7 million tons of wheat in Australia is damaged by pre-harvest sprouting annually and this represents an approximate loss of $19 billion to the Australian grower annually. In the United States there are numerous cases where sprout damage has occurred. In 1972, sprout damage was reported in 12% of the hard red spring wheat and 19% of the durum wheat produced in North Dakota (Anonymous, 1977). In Eastern Washington pre-harvest sprouting has occurred in 1940, 1941, 1968, 1971, 1973, 1977, and 1978 (Briggle, 1979). In 1968, Japan stopped buying U. S. soft white wheat for nine weeks due to a high incidence of sprouting in the wheat. The cost to the U. S. was $18 million in lost sales and $750,000 in compensation for damaged wheat previously purchased by the Japanese (Anonymous, 1978). In 1930, pre-harvest sprouting was a serious problem in the durum wheat region of North Dakota and the soft wheat areas of New York and Michigan.

The processor is also affected by pre-harvest sprouting in wheat. A slight rain can cause bleaching of the grain and may change the vitreous texture of the kernels to a more "mealy" one (Swanson, 1946). When the seed sprouts starch within the endosperm is broken down to sugars which are translocated to and used by the growing embryo. The flour from sprouted wheat will have lower falling number (high paste viscosity) and the bread made from this type of flour will have increased diastatic activity resulting in a sticky crumb, pale crust, and perhaps collapsed loaves (Anker and Geddes, 1944; Greer and Hutchinson, 1945; Belderok, 1968; Moss, et al., 1972).

A number of physiological, biochemical, morphological, and environmental factors have been suggested to have an input into preharvest sprouting, but this review will mainly discuss the environmental effects of pre-harvest sprouting in wheat. Where physiological, biochemical, or morphological changes occur within the wheat seed due to environmental changes, these factors will also be discussed.

LITERATURE REVIEW

Varietal Differences to Pre-harvest Sprouting

There are numerous reports in the literature showing varietal differences to pre-harvest sprouting in wheat (Harrington, 1932; Deming and Robertson, 1933; Nilsson-Ehle, 1914; Belderok, 1961; Wellington and Durham, 1958; Ching and Foote, 1961; Everson and Hart, 1961). Even the period of dormancy between wheat classes has been found to vary. Harrington and Knowles (1940) showed that bread type wheats maintained more dormancy during the first eight days of maturity and less thereafter when compared to durum wheats.

Harrington (1949) showed that the length of time for a spring wheat variety to lose its dormancy (90% germination in 10 days) varied from 10 days to over 60 days after maturity. He also found that the dormancy period for a variety was approximately 20 days longer when the seeds were tested unthrashed from the spike compared to using thrashed seeds. There were several varieties which showed no loss of dormancy due to thrashing, but these varieties were ones which showed the greatest amount of dormancy initially. This response to thrashed vs. intact seeds has been suggested to be due to germination inhibitors present within the chaff (Smith, 1948; Derera and Bhatt, 1980).

Figure 1 shows the varietal differences to pre-harvest sprouting that exist in wheat (Belderok, 1961). Staring is a white-grained variety while the other varieties are red-grained. Varieties may respond differently to their potential to sprout based on the year grown (Figure 2). These year-to-year differences may be due to environmental differences during seed development.

Changes in Soil Moisture During Development

The effects of soil moisture during wheat plant development on seed dormancy was examined by Belderok (1961) (Figure 3). He raised wheat plants in pots until the transition from the milky-ripe to the mealy-ripe stage of development. From this time on, one group of pots was allowed to dry out while another group of pots was regularly watered. There was no difference in the level of seed dormancy with the decrease in soil moisture. The major difficulty with this research results from the general way of controlling the soil water. There was no accurate measurement of the water potential for the plants while the seeds were at the various stages of development.

Changes in Relative Humidity During Seed Development

Belderok (1961) grew wheat plants at a relative humidity of 60-80% and transferred them to a high relative humidity (85-90%) for a 6-day period during either the flowering, the milk-ripeness, or the mealy-ripe stage of development. He found that there was no effect of relative humidity on the dormancy of the wheat seeds when compared to the control (Figure 4).

Changes in Temperature During Seed Development

The temperature the plants are being exposed to during grain development has been found to influence pre-harvest sprouting. Dry and sunny weather conditions during grain development and ripening result in a shorter dormancy period than moist and cool weather conditions for rice (Ghosh, 1962), wheat (Greer and Hutchinson, 1945; Belderok, 1961; Belderok, 1956) and barley (Kivi, 1966).

Fritz (1933-34) investigating weather patterns in various regions of Austria concluded that warm weather in July and August followed by a period of rainfall to be ideal for pre-harvest sprouting. Greer and Hutchinson (1945) found that if hot, dry weather, which hastens maturation, is followed by rain, the conditions for pre-harvest sprouting are most favorable. On the other hand, wheat grown during a cold, damp growing season is likely to show less tendency to sprout in a rainy harvest.

A detailed study to examine the effects of temperature during seed development on pre-harvest sprouting has been done by Belderok (1965); he grew wheat plants at a 18C:12C day:night temperature and at various stages of seed development transferred groups of plants to a 25C constant temperature chamber for 6 days. The dormancy period for plants grown at 25C for 6 days during the flowering or milk-ripe stages of development were very similar to the no heat treatment (Figure 5). However, there was a significant reduction in the dormancy period for plants grown for 6 days at 25C during the transition from milk to mealy ripe or the mealy ripe stage of development. Belderok classified the transition from milky ripe to mealy ripe stage to be when the covering layer of the seed starts to yellow.

Belderok (1965) also found that wheat plants grown for 1 or 3 days at 25C during the mealy ripe stage showed only minor differences in their 3-day germination percentage as compared to the control (18C day - 12C night) (Figure 6). But keeping the plants at 25C for 6 days showed a marked reduction in the length of seed dormancy.

More recent works disagree with Belderok's conclusions and suggest that cool temperatures during grain development may be responsible for sprouting. Lallukka (1976) found that sprouting may take place immediately after or even before ripening in some varieties of wheat grown under Finnish climates. He grew two varieties of spring wheat to the yellow ripe stage of development at 12 and 24C at 90 percent relative humidity. The grain ripened at 12C had lower falling numbers than that ripened at 24C (Figure 7). Similar results were found under natural field conditions. He found that the end of dormancy was related to the onset of the yellow ripe stage of development and that the decrease in falling numbers were greatly influenced by the weather conditions after this stage.

Dobben (1947) exposed wheat plants which had been grown outside to temperatures of 35-40C for seven days during the flowering and milk-ripeness stage of development. The plants were then allowed to mature outside. His finding showed that the wheat exposed to the heat during flowering showed a lower degree of sprouting in the spike.

Changes in the Moisture Content of the Seed

Early work by Belderok (1961) examined the effects of moisture content of the seeds at harvest on how well the seeds will germinate. He found that the lower the moisture content of the seed at harvest, the shorter the dormancy period (Figure 8).

More recently, King and Gale (1979) found that the rate at which detached, immature grains dried influence their capacity to produce alpha-amylase. Slow drying (50% water loss in 10 days) was most favorable for the establishment of alpha-amylase synthesis potential. They found that rapid drying (50% loss of water in 3 days) reduced alpha-amylase synthesis potential by 80%, thus rapidly dried grain with a low apparent alpha-amylase potential merely required a longer incubation period prior to germination. Varieties were shown to have large differences in response to drying conditions, both in their maximum potential, and in their response profile. They suggested that these varietal and seasonal drying differences could confuse year-to-year comparison in the field.

Mitchell, et al (1980) found that the loss of water from the pericarps begins much earlier than in the remainder of the seed and this drying of the pericarps was correlated with the onset of germination. They reviewed several theories for this onset of germination: (1) drying may increase water permeability, (2) drying may increase oxygen permeability, (3) drying may decrease the mechanical strength of the covering layers, and (4) drying may destroy germination inhibitors present within the paricarps.

Moss, et al (1972) found varietal differences in the rate of formation of alpha-amylase of five white wheats. They used a rain simulator to demonstrate the effects of rain and temperature on pre-harvest sprouting. While the white wheats showed a significant decline in falling numbers (increased alpha-amylase activity) and an increase in sprouting with the addition of rain, the red wheat varieties showed a range of responses from no effect to a significant decline after the rain similation. This suggests that there is a variety x treatment interaction. They concluded that high temperatures during ripening and prolonged wetting lead to increased deterioration of the seed over that of low temperatures or wetting for short durations.

A paper by Gordon, et al (1977), where they used a rain simulator was used to stimulate pre-harvest sprouting, showed that endosperm degradation was well advanced before alpha-amylase activity had increased from base level.

Germination Temperature on Seed Germination

Numerous authors have shown that grains that are in a dormant state will germinate readily at low temperatures (10-15C) (Harrington, 1923; Hutchinson, et al, 1948).

Reddy, et al (1979) showed that winter wheat varieties exhibited varying degrees of dormancy when germinated at 20C and 26.6C, but the varieties could be distinguished into dormant and non-dormant at 15.5C. They also found lower alpha-amylase activity at higher ripening and germination temperatures.

Moisture Conditions Available for Seed Germination

Belderok (1961) examined the quantity of water needed for 50 seeds to germinate in petri dishes after harvest. He found that the rate of germination was largely dependent on the quantity of water available in the dish and that there was an optimum required for germination (Figure 9). He also discovered that the amount of water necessary to attain optimum germination decreased as the time from full ripeness increased. For example, for the red seeded variety, Mado, from full ripeness to 2 weeks after full ripeness, 4 mls of water were needed for optimum germination, 6 weeks and

9 weeks after full ripeness, 3 mls and 2 mls of water, respectively, were needed for optimum germination. Belderok suggested that a variety's susceptibility to sprouting was a combination of the variety's dormancy and the quantity of water needed for it to germinate. This becomes important when rains occur during harvest. Many times the quantity of rain may not be optimum to start the seeds to germinate, but it may delay the harvest process. This delay in harvesting may make the grain require less moisture to germinate the next time it rains. Therefore, the rains at harvest are not only important from the standpoint of supplying moisture to the seed for germination, but also the rains delay the harvesting process, thus making the seeds require less moisture if it rains later.

Relative Humidity During Seed Storage

Kretovich, et al (1940) exposed wheat samples at harvest to air ranging in relative humidity from 5 to 16%. They found that as the grains dried further, their potential to germinate increased.

Wellington (1956) stored red and white wheat seeds at the harvest ripe stage of development at various relative humidities (50, 75, 85-90, and 100%) (Figure 10). He found that the percent germination for red wheat seeds was 7% initially and increased for all of the relative humidities with the largest increase when the storage relative humidity was the lowest. The percent germination at harvest ripe for the white wheat seeds was 88 percent and when the seeds were stored at saturated conditions there was a small reduction in percent germination. He also found that when the moisture content was reduced during storage to a level below that of the harvest ripe stage, there was a marked increase in the percent germination of the grains. He suggested that the covering layers of the pericarps of red grain provide an inhibitory effect to seed germination. The rate of desiccation which occurs after the grains reach the harvest ripe stage of development is dependent on the humidity of the atmosphere in the field. He suggested that this, in turn, determined the quantity of seeds which will sprout in the ear.

Wellington and Durham (1958) suggested that the climatic conditions responsible for sprouting were enough rain to saturate the ear followed by a period of high atmospheric humidity to allow for the transfer of moisture from the glumes to the grain. A heavy rain is not enough, if the evaporative demand of the atmosphere increases rapidly after the rain, so that the moisture held in the chaff is lost to the atmosphere without raising the moisture content of the seed.

Storage Temperatures of the Seed

Larsen, et al (1936) showed that there was a great difference in wheat varieties to the length of their after-ripening period. They found that the lower temperatures (0C) of the storage resulted in a longer after-ripening period. Harvesting the plants while still unripe generally increased the length of the after-ripening period.

Similar results were found by Belderok (1961) where there was a reduction in the dormancy period as the storage temperature increased from 8C to 25C (Figure 11).

Secondary Dormancy

McEwan (1956-58) found that laboratory sprouting tests did not duplicate field sprouting. Likewise, Belderok and Habekotte (1979) found that the duration of dormancy under field conditions was much longer than under laboratory conditions (18C and low relative humidity) (Figure 12). The duration of dormancy (defined as the time between the first day of harvest ripeness and the day on which 50% of the kernels germinate) varied from year to year and variety to variety. Their data suggested that lower night temperatures tended to prolong the dormancy period and in some cases bring about a secondary dormancy to the wheat seed. They suggested that this secondary dormancy was due to low minimum temperatures and high relative humidity.

The occurrence of secondary dormancy may possibly explain why the danger of sprouting is not as high as germination tests suggest under conditions of relative cold and moist weather at harvest time.

Fischnich, et al (1959) observed that the winter wheat cultivar "Kimpaus Bastard II" harvested in the beginning of November was in a state of secondary dormancy, but not when harvested in August or September. They suggested that the secondary dormancy was caused by a combination of low field temperature (about 0C) and a high moisture content of the grain.

Warning System

Procedures to predict a sprouting forecast have been developed and are used in several European countries. Belderok (1968) suggested that the length of the dormancy period depends on the variety and on the accumulated temperature during the dough stage. With the critical accumulated temperature for a variety and the current temperature data the risk of sprouting in the ear can be determined. This way farmers would know which varieties have the greatest chance of sprouting and should be harvested first. The accumulated temperature was calculated as the sums of the daily temperatures above 12.5C (maximum + minimum)/2-12.5C) reached during the dough ripeness stage till full ripeness. (Belderok, 1965). This procedure is used in the Netherlands and West Germany.

Grahl and Schrodter (1973) tested Belderok's accumulated temperature theory using several varieties of wheat and locations in Sweden (Figure 13). They were unable to find any relationship between temperature sum and the duration of dormancy for any of the varieties examined. They suggested that the discrepancy in the results between their field study and Belderok's greenhouse experiment may be due to high temperatures for one to several days after the seeds reached morphological ripeness in Belderok's study. High temperatures during storage have been shown to decrease dormancy.

More recently Schrodter and Grohl (1978) have developed a method of forecasting sprouting by stressing the influence of weather factors during the last week before morphological ripeness. They found that at a constant temperature the dormancy period becomes shorter as the relative humidity of the air decreases.

Olsson and Mattson (1976) tested Belderok's (1965) forecasting procedure under Swedish conditions. They concluded that:
(1) Cultivars varied in the length of their dormancy period;
(2) High temperatures during and after ripening seemed to shorten the dormancy period; however, other climatic factors should also be considered; and (3) The influence of the accumulated temperatures during the dough stage on the duration of dormancy varies from year to year and from place to place. Overall, they did not feel that accumulated temperatures could be used as an efficient warning system.

Working with barley, Reiner and Loch (1976) found two temperature sensitive periods which correlated with germination capacity. The first sensitive period was between 12 and 16 days after ear emergence where low temperatures have the effect of reducing post-harvest dormancy. The second sensitive period was between 30-41 days after ear emergence (mealy-ripe stage) during which high temperatures reduced post-harvest dormancy.

Conclusion

Pre-harvest sprouting is a serious problem in many wheat producing areas of the world. Wheat that has sprouted usually results in reduced yields and test weight values, thus the producers receive a lower price for their product, and the sprouted wheat results in a poor quality product by the processor.

A number of factors have been suggested to be important in preharvest sprouting of wheat. Environmental conditions that the wheat seed is exposed to during development and prior to harvesting, are important in determining the level of pre-harvest sprouting.

In general, rains at harvest will lead to the seeds germinating in the spike if the seeds maintain a saturated state for a long enough period of time.

The largest factor to consider in trying to understand the effect of environmental conditions on pre-harvest sprouting is the relationship between varietal differences and these conditions. There was generally a variety x environment interaction for many of the conditions examined.

During seed development the soil moisture and the relative humidity which the plant is exposed to had no influence on pre-harvest sprouting. Change in air temperature during seed development have been suggested to play an important role in determining the potential of sprouting. There are several conflicting reports and disagreements in the literature as to whether low or high temperatures during development stimulate sprouting.

The environmental conditions prior to full ripeness may play a role in determining the potential for sprouting, but the conditions after full-ripeness probably contribute more to possible seed germination. Usually lower germination temperatures will cause dormant seeds to germinate if water is available, but lower storage temperatures have been found to lengthen the dormancy period in seeds. Also, if seeds are allowed to dry to a lower moisture level, the potential to germinate is increased. However, low temperatures and high moisture content of the grain have been shown to result in a state of secondary dormancy for the seeds.

Warning systems are now being used in several European countries to predict the potential for sprouting. There are disagreements in the literature as to whether these systems really work.

Additional research is needed to better understand how the environmental conditions that the wheat seeds are exposed to during development and after full-ripeness influence pre-harvest sprouting.

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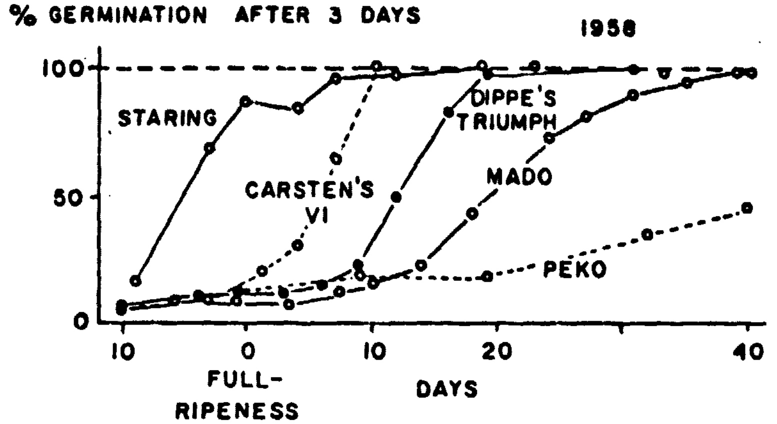
FIGURE 1

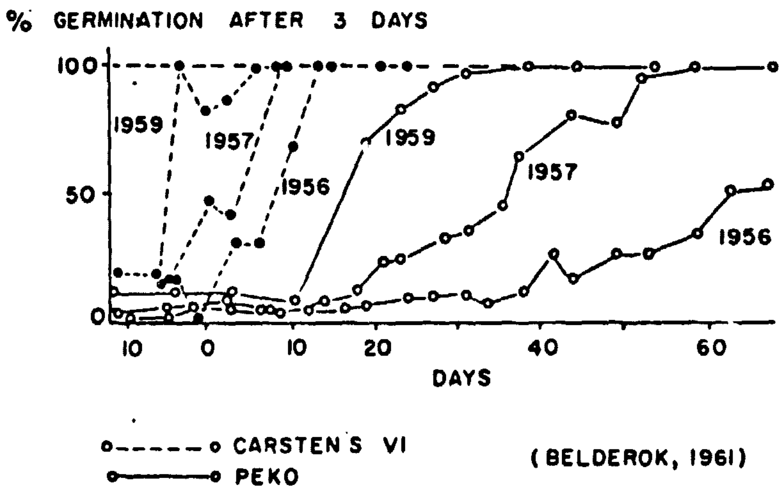
VARIETAL DIFFERENCES IN PREHARVEST SPROUTING



(BELDEROK, 1961)

FIGURE 2

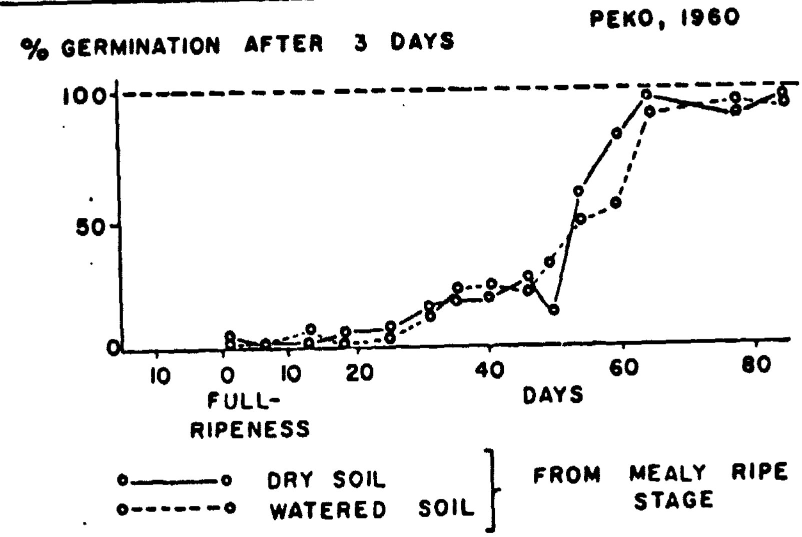
VARIETY * YEAR INTERACTION ON PREHARVEST SPROUTING



(BELDEROK, 1961)

FIGURE 3

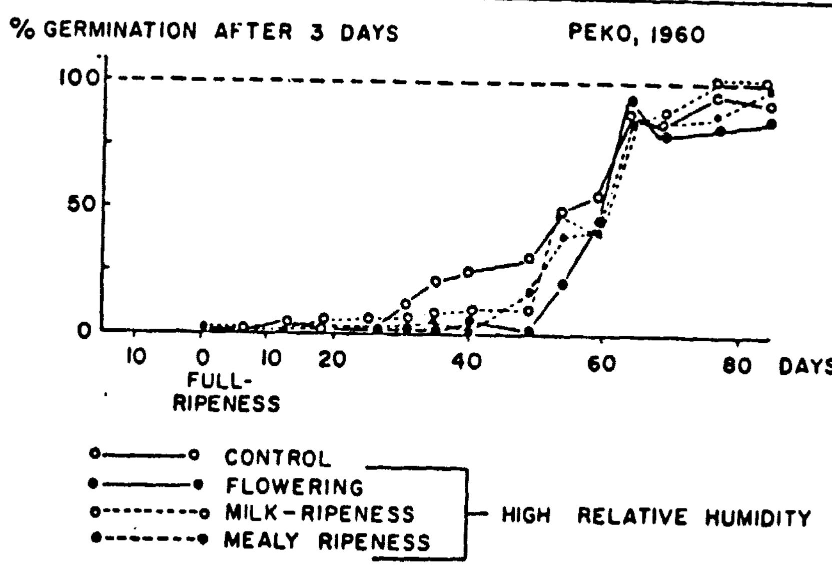
EFFECT OF SOIL MOISTURE ON PREHARVEST SPROUTING



(BELDEROK, 1961)

FIGURE 4

EFFECT OF RELATIVE HUMIDITY ON PRE-HARVEST SPROUTING



(BELDEROK, 1961)

FIGURE 5

EFFECT OF ELEVATED TEMPERATURE (25C) AT VARIOUS DEVELOPMENTAL STAGES ON PRE-HARVEST SPROUTING.

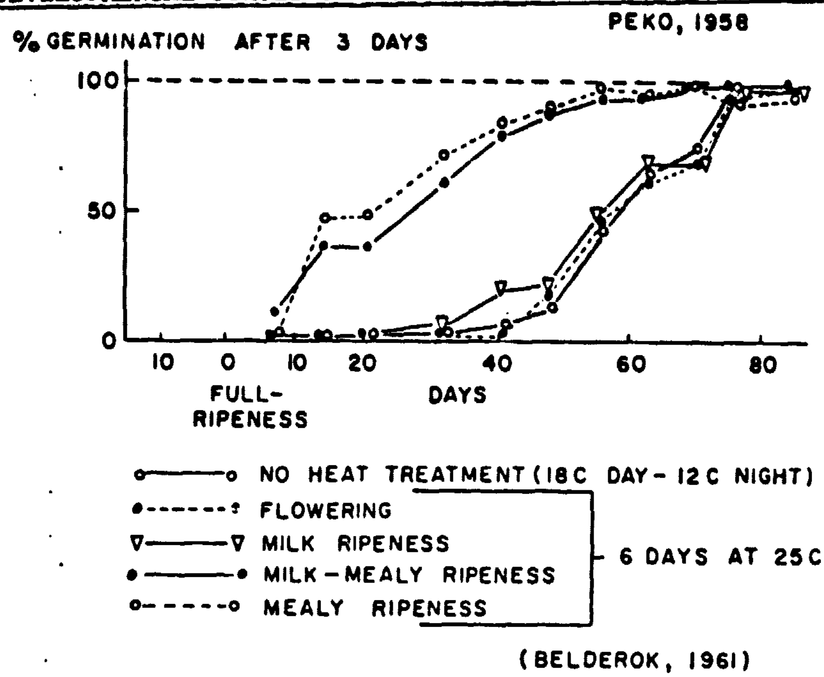


FIGURE 6

EFFECT OF THE LENGTH OF TIME AT 25C DURING THE MEALY RIPE STAGE OF DEVELOPMENT ON PRE-HARVEST SPROUTING.

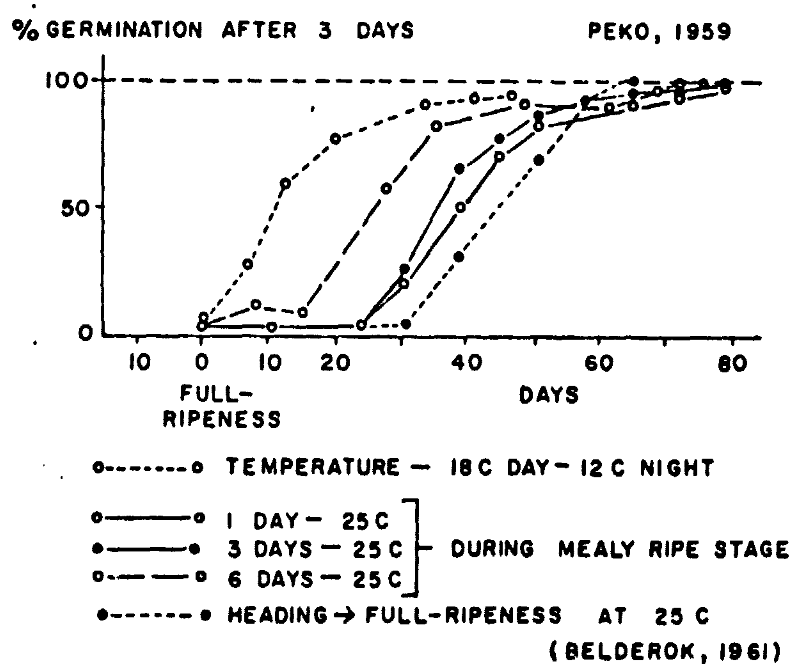
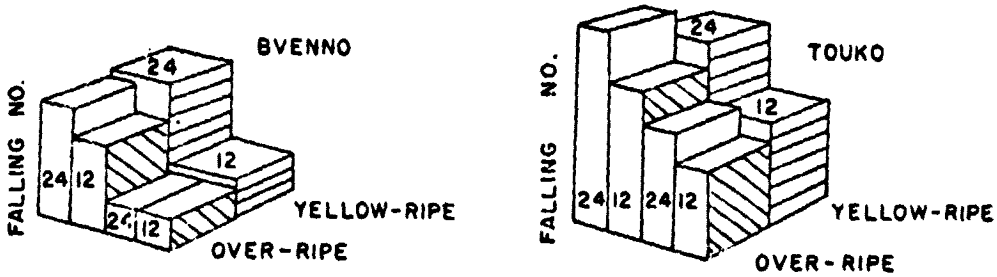


FIGURE 7

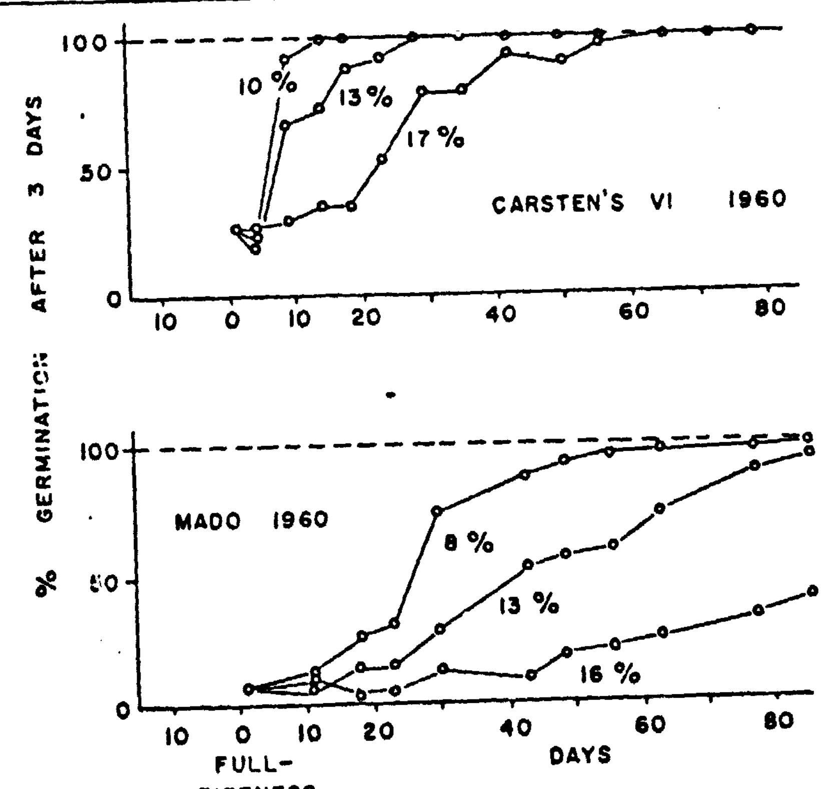


EFFECTS OF TEMPERATURE (°C) DURING RIPENING (MILK TO YELLOW RIPENESS) AND OVER-RIPEING ON FALLING NUMBER OF SPRING WHEAT.

(LALLUKKA, 1975)

FIGURE 8

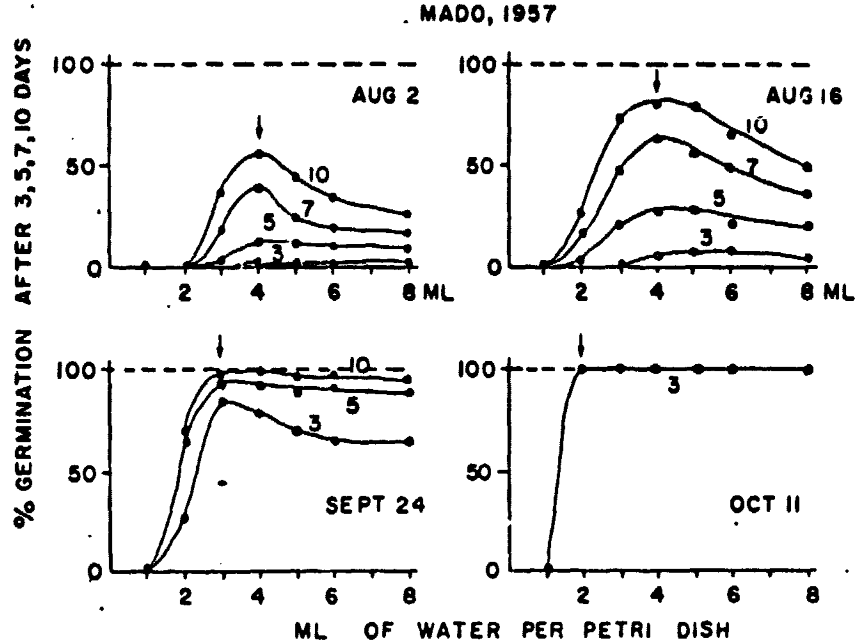
EFFECT OF MOISTURE CONTENT DURING STORAGE ON DORMANCY



(BELDEROK, 1961)

FIGURE 9

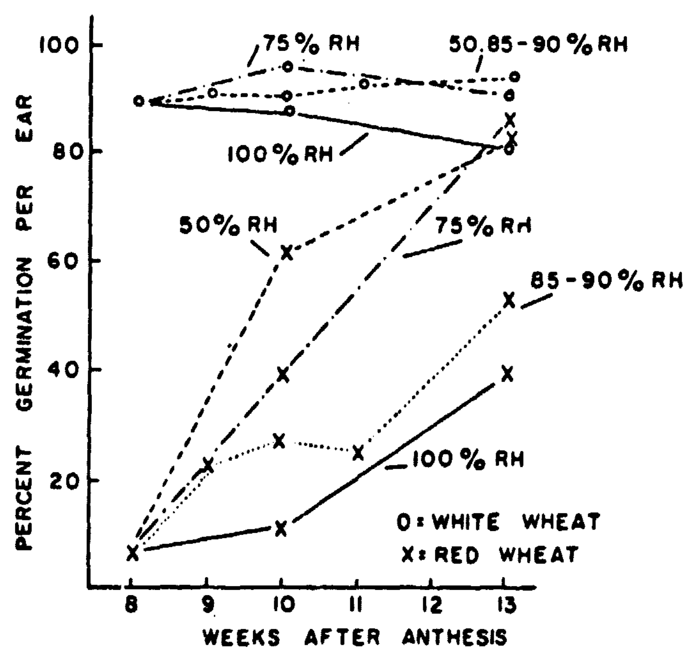
QUANTITY OF WATER NEEDED FOR GERMINATION



(BELDEROK, 1961)

FIGURE 10

STORAGE AFTER FULL RIPE STAGE AT VARIOUS RELATIVE HUMIDITIES



(WELLINGTON, 1956)

FIGURE 11

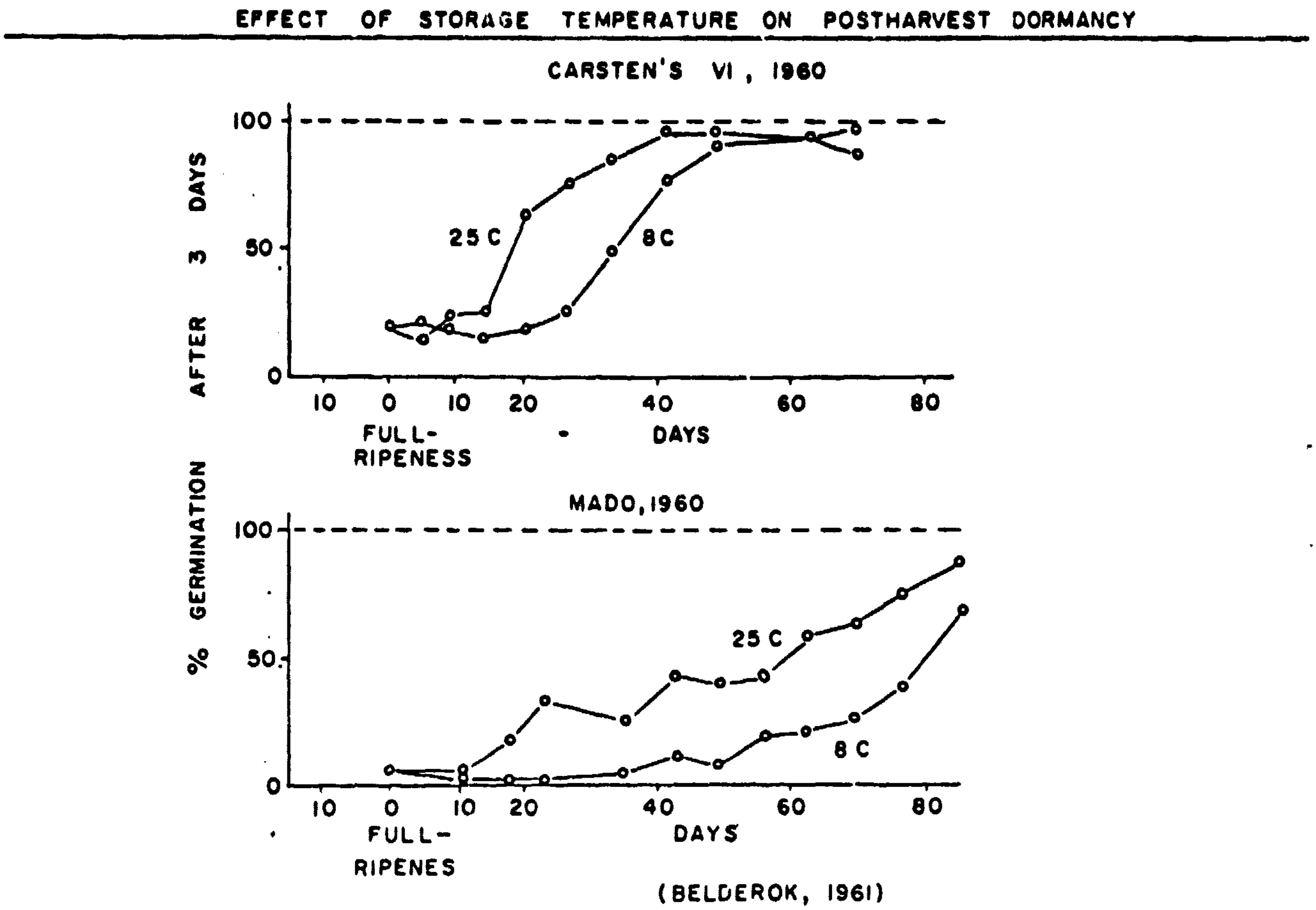


FIGURE 12

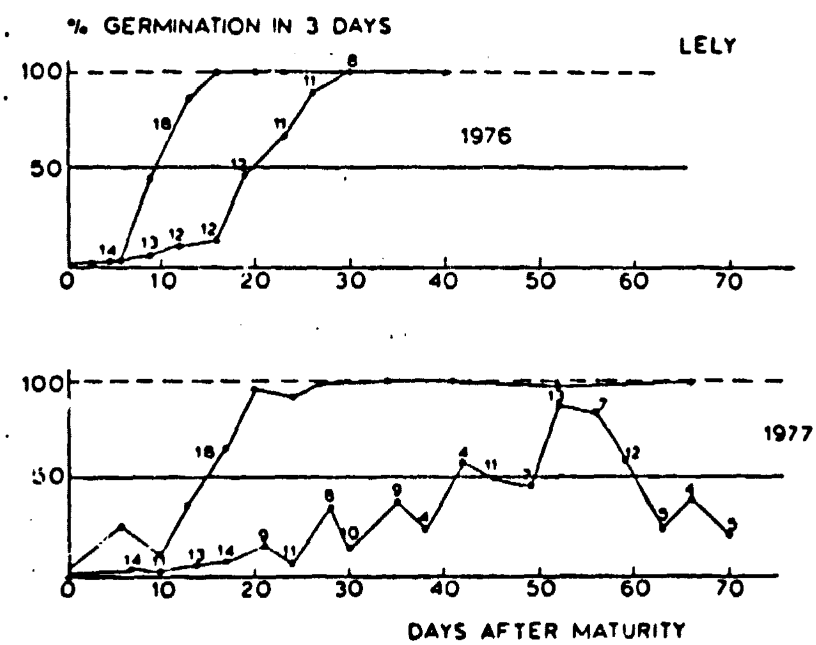
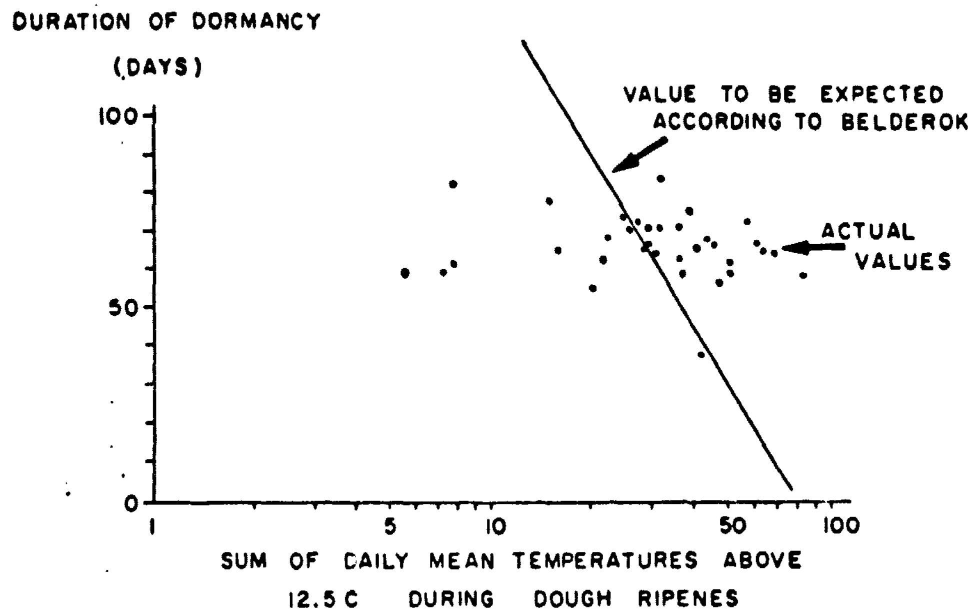


FIG. 1. Changes in germinative energy of grains of the Lely cultivar stored in the laboratory (curves on the left) and taken from the unharvested crop at regular intervals (curves on the right), 1976 and 1977. At each point in the figure the minimum temperature of the day is given. BELDEROK AND HABEKOTTE (]979)

FIGURE 13



(GRAHL AND SCHRODTER, 1973)