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INFLUENCE OF ENVIRONMENTAL FACTORS DURING SEED DEVELOPMENT AND AFTER FULL-RIPENESS ON PRE-HARVEST SPROUTING IN WHEAT

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16. Abstract

A review of the literature on the influence of the environment on pre-harvest sprouting in wheat was submitted earlier. This report is a summary of our results on environmental and genotypic factors influencing preharvest sprouting. Data is still being collected and analyzed. Later these findings will be presented in manuscript form, but this report will mainly summarize our findings and suggest other possible areas where additional research is needed.

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INFLUENCE OF ENVIRONMENTAL FACTORS DURING SEED DEVELOPMENT AND AFTER FULL-RIPENESS ON PRE-HARVEST SPROUTING IN WHEAT.

A.J. Ciha[1], H. Murray[2], M.G. Hagemann[3], and W.A. Goldstein[3]

A review of the literature on the influence of the environment on pre-harvest sprouting in wheat was submitted earlier. This report is a summary of our results on environmental and genotypic factors influencing pre-harvest sprouting. Data is still being collected and analyzed. Later these findings will be presented in manuscript form, but this report will mainly summarize our findings and suggest other possible areas where additional research is needed.

Seven winter wheat cultivars showed a wide range in their ability to germinate at various temperatures at harvest ripeness (Figure 1). Brevor and Greer showed the widest range in their 7-day germination percentage of the cultivars examined. At elevated temperatures the cultivars did not germinate even though moisture was not limiting. This phenomenon is known as high temperature seed dormancy (George, 1967). At temperatures representative when rain occurs (below 25C), the majority of the cultivars examined showed more than 50% germination after 7 days. Brevor showed only limited germination until below 20C.

The level of post-harvest dormancy in winter wheat after full-ripeness was dependent on the genotype and number of weeks after full-ripeness (Figure 2). The cultivars showed a wide range in their loss of post-harvest dormancy. Greer showed no dormancy while Wanser and Daws lost the majority of their dormancy within 15 weeks after harvest. On the other hand, Brevor, a very dormant cultivar, showed only 25% germination 36 weeks after harvest, indicating that Brevor was still highly dormant.

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These findings suggest that winter wheat cultivars express a wide range in initial level of dormancy and will lose the dormancy at differential rates. Our results indicate the importance of performing the sprouting tests for dormancy immediately after harvest and the importance of examining the specific cultivars of interest.

Several experiments were established to examine the influence of temperature and moisture on germination after a seed reaches full-ripeness. In each case seeds or individual heads were harvested at full-ripeness. The seeds were removed from the heads by hand threshing to prevent damage to the seed coat. In one group of experiments the seeds were placed in either air-tight glass jars or heads were placed into plastic bags and stored at controlled temperatures (-10, 10, 20 and 30C) for 8 weeks. At 2-week intervals a germination percentage and promptness index (George, 1967) was obtained for each sample and a scoring of the germination of seeds in the intact head (Table 1) after moistening was determined. In a few cases different levels of moisture were added to the petri dishes used for the seed germination to quantify the effect of moisture on the germination percentage after the loss of dormancy.

Seeds more readily lost dormancy when stored at a higher temperature than at lower temperatures (Figure 3). In general, the 30C storage temperature resulted in a greater loss of dormancy (measured by an increase in the percent germination after 7 days) than the 20 and 10C storage temperatures. Increasing the moisture level during germination resulted in enhanced germination after 7 days (Figure 3). This can be seen by examining the germination levels with 6 and 8 mls of water in each petri dish. Again the 15C gave better germination percentage than at 30C. Varying the moisture levels resulted in a slight change in the seed moisture but the difference was only 2-4% (Figure 4). While seed moistures were very close for days 4-6 for each of the three watering levels, there were a few percentage differences in seed moisture during the early stages of uptake. Both the 4 and 6 ml water levels at 12 hours showed a lag phase in water uptake which was not present in the 8 ml sample. The lack of germination at 30C was not due to the lack of moisture since the seed moisture at 30C was consistently greater than at 15C.

Cultivars showed a wide range in their percent germination at various moisture levels as the storage time was lengthened (Figure 5). As the length of storage increased there was a decrease in the quantity of moisture required to achieve a specific germination level. This data would suggest that the longer the wheat seeds remain in the field, the more dormancy is lost, and less moisture is needed to germinate the seed. For example, with Moro at full ripenes (T=0), the 8 ml of water gave a percent germination of approximately 80%. After 4 weeks of storage (T=4) 80% germination was achieved with only 6 ml of water and after 8 weeks of storage (T=8) only 4 ml of water was needed to reach 80% germination. With the more dormant cultivar , Brevor, increased germination with increase in moisture and storage was delayed.

The percent germination and promptness index of grain of winter wheat cultivars after various lengths of storage time and moisture levels were found to be influenced more at 30C than 15C (Figure 6). This indicates the expression of dormancy at 15C is very low, while at 30C dormancy is high. Increases in moisture level during this period resulted in increases in promptness index and percent germination.

The environment in which the grain develops influences the level of dormancy at full-ripeness and the loss of dormancy after storage (Figure 7). Grain of Nugaines grown at Pendleton, Oregon showed the lowest level of dormancy (greatest percent germination) at full-ripeness when compared to seed grown at Pullman and Central Ferry, WA. Grain grown at Central Ferry tended to lose its dormancy slower than grian grown at Pullman.

Cultivars representing a range in susceptibility to pre-harvest sprouting were seeded at several environmentally different locations within major wheat producing areas of the Pacific Northwest (Table 2). Seed development and temperature during the various developmental stages were followed. Percent germination and promptness index were determined on grain tested at harvest ripeness and after 8 weeks of storage at four different storage conditions. The percent germination for all locations was consistently lower at a germination temperature of 30C than 15C (Table 3). Grain from Ferdinand, ID showed the greatest germination percentage at 15C, but the lowest at 30C at harvest ripeness. However, Ferdinand grain showed the most rapid loss of dormancy (measured by increased percent germination) from harvest ripeness to 8 week storage at 30C. Pullman grain showed the second fastest loss of dormancy followed by grain from Central Ferry, WA and Pendleton, OR. These results showed that the grain grown under the cooler environmental conditions have the greatest quantity of initial dormancy but lose that dormancy the quickest. These cooler locations are also the ones which receive more precipitation at harvest, hence they are thus more vulnerable to sprout damage than the warmer locations. The loss of dormancy for individual cultivars at specific locations is shown in Table 5.

The greatest loss of dormancy occurred after the 8 week storage period at 30C. Very little loss of dormancy occurred at -10, 10, or 20C storage conditions. The literature suggests that volatile fatty acids of chain lengths C_6-C_{10} present in the seeds may be related to seed dormancy and that at higher temperatures the fatty acids evaporate from the seeds (Berrie et al., 1979).

Differences in promptness index at harvest ripeness and after 8 weeks of storage showed that these traits are significantly influenced by location and storage temperature (Table 3). The general trends for promtness index followed that of percent germination. The 30C storage conditions produced the greatest amount of seed dormancy over the 8 week storage period. Also, the cooler environments (Ferdinand, ID and Pullman, WA) showed the most rapid loss in dormancy.

In another field experiment three winter wheat cultivars ('Moro' - soft white club, 'Nugaines' - soft white common, and 'Mironovskaya 808' - a hard red) were grown under various fertility levels and the heads were artifically wetted at three stages of grain development. The heads were wetted for approximately 30 minutes at 8pm for 7-10 days during each seed developmental stage. Preliminary amylograph data for the cultivar, Moro, is shown in Table 5. Wetting the heads at either the milky, soft dough, or hard dough stage of development for Moro resulted in a lowering of the starch quality as measured by the amylograph over that of no watering. Wetting at all three stages resulted in a continued decrease in starch quality. The other cultivars which vary in their level of seed dormancy have not yet been analyzed. The type or quantity of fertilizer used had little effect on starch quality measured by amylograph (Table 5).

There was little effect of wetting on yield or the yield components for the cultivars examined (Table 6). However, test weight values were significantly lowered with continuous watering over that of the control, while watering during the soft dough or hard dough stages of development resulted in no significant reduction from the control.

Visual sprout damage was the greatest with the wheat cultivar, Moro, but watering at the various stages had little effect on the quantity of visual sprouting (Table 7). This was probably due to the fact that the heads did not receive water at duration long enough to stimulate sprouting.

The effect of wetting on the percent germination and germination index for three winter wheat cultivars at harvest ripeness was determined (Table 9 and 10, respectively). All cultivars showed good germination at 15C while the 30C germination temperature revealed different levels of dormancy. Mironovskaya 808 was the most dormant with Moro having the least dormancy and Nugaines showing an intermediate level of dormancy.

The germination index did suggest that at 30C Moro showed a slight stimulation of germination with wetting at the hard dough stage and with continuous wetting, but the other cultivars and wetting times did not show any effect on percent germination and germination index.

To determine the effects of moisture on harvest ripe winter wheat seed, hand threshed seeds and intact heads were artifically wetted for various lengths of time and various wetting and dry cycles. Hand-threshed seeds or intact heads of four winter wheat cultivars (Moro, Mironovskaya 808, Wanser and Stephens) were allowed to take up moisture for 2, 4, 6, 12, 24 and 48 hours. Seeds or heads were allowed to air dry after the wetting cycle. Some of the material was then exposed to one or two additional wetting cycles. Measurements of percent water uptake, scoring of germinated seeds, and level of alpha-amylase were determined.

The percent moisture and scoring value for the winter wheat cultivars with various wetting and drying cycles are shown in Figures 8a-d. In general, the seeds took up a greater quantity of water with the second and third wetting cycle than they did with the first wetting cycle. As the seeds started to sprout at the longer wetting times, the percent water for the seed material increased (ex. Moro) (Figure 8c). Also, the scoring of germinated seeds increased with more wetting cycles and increased length of wetting (ex. Moro) (Figure 8c) again showing the increased sprouting. On cultivars showing greater levels of dormancy than Moro, the scoring and percent moisture in the seeds did not show as large of an increase with increased wetting cycles and length of wetting cycle. In this study, threshed seeds in petri dishes were maintained in 20C incubators while intact heads were subject to greenhouse conditions. Under greenhouse conditions daytime temperatures can exhibit large fluctuations in temperature which explains the larger variations in percent moisture and scoring of germinated seeds observed with the greenhouse study.

Measurement of alpha-amylase level for the seeds in the petri dishes indicated that there was little effect on alpha-amylase until after 48 hours of wetting (Figure 9a-d). Additional wetting cycles increased the alpha-amylase level over that of one cycle. Once the alpha-amylase was present in the seed, air drying of the seed did not remove the alpha-amylase. The alpha-amylse remained in the seed and was ready to cause additional damage when the next wetting period occurred.

The cultivars responded differently with respect to alpha-amylase levels after wetting and drying cycles. Mironovskaya 808, the most dormant cultivar, showed a slower increase in alpha-amylase level with additional wetting (Figure 9d). This can especially be seen when comparing Mironovskaya 808 and Stephens (Figure 9a). Stephens showed a much larger increase in alpha-amylase concentration after the third 48 hour wetting cycle when compared to Mironovskaya 808.

Seeds which had gone through the wetting and drying cycles were germinated for 7 days at 15 and 30C to determine the percent germination and germination index for the seeds (Figure 10a-d). In general, once the seeds had been exposed to wetting cycles there was an increase in the percent germination and germination index. Lengthened wetting periods increased (or stimulated) the germination index and percent germination. The response was partially cultivar dependent with Wanser showing the greatest response. With some germination temperatures and cultivars, the third wetting for 48 hours resulted in a reduction in percent germination and germination index due to the fact that some seeds in these treatments had already achieved advanced sprouting. Once these sprouted seeds were dried, they did not regerminate, thus resulting in a lowering of the percent germination and germination index even though the alpha-amylase level continued to climb.

Another group of hand threshed seeds of four winter wheat cultivars (Mironovskaya 808, Brevor, Stephens, and Moro) were germinated at 10, 20, and 30C for 144 hours. Moisture percentage, scoring of germinated seeds, and alpha amylase content were determined.

In general, after 72 hours the seeds at 20C started to show an increase in their percent moisture. This increase was associated with the seeds starting to show some degree of visual sprouting. As more radicals and coleoptiles appeared on the seeds (increased scoring), a greater proportion of the dry weight was accounted for by plant tissue which had a greater moisture percentage than seeds.

The more dormant the individual cultivars were, the longer was the period of time prior to the appearance of plant growth. The moisture uptake in the early stages of imbibition was relatively constant across cultivars. The higher temperatures resulted in a small increase in water uptake (percent moisture) over that of the cooler temperature.

The level of alpha-amylase started to increase prior to 48 hours in the seed (Figure 12 a-d). While the percent moisture and scoring for the seeds at 10 and 30C were similar, the production of alpha-amylase in the seed at 30C was zero for the 144 hour period.

Mironovskaya 808 and Moro produced the largest quantity of alpha-amylase while Stephens produced an intermediate level and Brevor produced the lowest. Brevor was the most dormant cultivar used in the study.

In summary, the following points can be made from this study:

1. Winter wheat cultivars varied in their level of dormancy and the speed in which they lost their dormancy after reaching full-ripeness.
2. Seeds grown in cooler environments during grain fill tended to have the highest level of dormancy at harvest ripeness, but their dormancy was lost the quickest.
3. Artificial wetting at milky, soft dough or hard dough lowered the starch quality of grain measured by amylograph and lowered the test weight of the grain over that of no wetting, but had no effect on yield or yield components.
4. At 30C alpha-amylase activity was inhibited even though the seeds imbibed water at a similar rate as seeds at 10 and 20C and showed visual sprouting.
5. The loss of dormancy by storage or by leaving the grain in the field had a large influence on various germinative tests (temperature when seeds will germinate, rate of germination, etc.).

6. Once the enzymatic (alpha-amylase) processes start due to the uptake of moisture, alpha-amylse remained at that level even after drying.
7. Seeds which have initially taken up water imbibed water faster with subsequent wettings. Also, the level of alpha-amylase production increased in some cultivars after the second wetting.
8. Temperature of the seed at the time of imbibition had a large influence on how well the seeds germinated.

These results indicate that geographic areas differ in the degree of dormancy achieved by grain of specific genotypes. This difference in dormancy is related to temperatures during grain fill. Cool temperatures imparted greater dormancy, but seeds produced in these cooler regions lost dormancy more rapidly than seed from warmer regions. Frequent wettings had a more detrimental effect than infrequent wettings of greater amounts of water. This helps to explain why cool foothill regions are more vulnerable to sprout damage than warmer regions of low elevation. The greater the time interval between grain ripeness and the occurrence of rain, the greater is the opportunity of sprout damage.

Implications of our findings are that the potential sprout damage of grain could probably be predicted for a given production area by monitoring 1) daily temperatures during grain fill, 2) amount, duration, and frequency of precipitation which occurs after grain fill, 3) daily temperatures prevailing after grain ripeness, 4) time elapsed between grain ripeness and precipitation event, and 5) knowledge of cultivar inherent dormancy potential.

While this set of experiments gave some preliminary results on the effects of environmental conditions during grain fill and after full-ripeness on pre-harvest sprouting, there are still a lot of questions left unanswered.

1. How do extended periods of wetting during grain fill influence the loss of dormancy and changes in the starch quality? In this study, very limited moisture at milky, soft dough, and hard dough resulted in a significant change in some cultivars. What effect does wetting during grain fill have on the level of dormancy present in the seed at harvest and the loss of dormancy?

2. The influence of shorter wetting cycles after a seed has been wetted for 48 hours needs to be examined. This study showed a large increase in alpha-amylse activity after the second and third wetting of 48 hours. What needs to be examined are shorter wetting cycles after a 48 hour cycle. Also, shorter time segments need to be examined to more clearly define at what time alpha-amylase starts to develop within a seed after wetting. Is the level of alpha-amylase cultivar and/or temperature dependent?
3. How does the drying period after a rain influence alpha-amylase and the loss of dormancy within a cultivar? This study showed relatively no change in alpha-amylase after drying of the seed. How would different periods of drying or temperatures during drying influence the loss of dormancy and the levels of alpha-amylase?
4. The most popular cultivars for a specific region need to be examined to determine the effects of environment on the level of pre-harvest sprouting and loss of dormancy. This study showed a strong influence of specific generalities for all wheat cultivars from examination of a single cultivar.
5. Effects of temperature on sprouting and alpha-amylase need to be more closely examined at smaller temperature increments. This is especially true for temperatures close to those experienced during and after rainfall.

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George, D.W. 1967. High temperature seed dormancy in wheat. Crop Sci. 7:249-252.

LIST OF FIGURES

Figure 9. Alpha-amylase activity (dextrinizing units/gm, du/gm) for winter wheat after an artificial wetting period of 2, 4, 6, 12, 24, or 48 hours with 2-3 wetting cycles performed in petri dishes for Stephens (a), Wanser (b), Moro (c), and Mironovskaya 808 (d). An air drying occurred between each wetting cycle.

Figure 10. Percent germination and promptness index after 7 days at the germination temperatures of 15 and 30C for Stephens (a), Wanser (b), Moro (c), and Mironovskaya 808 (d).

Figure 11. Percent moisture and scoring after 144 hours of germiantion at 10, 20 or 30C for Mironovskaya 808 (a), Brevor (b), Stephens (c), and Moro (d).

Figure 12. Alpha-amylse (du/gm) after 144 hours of germination at 10, 20, 30C for Moro (a), Stephens (b), Mironovskaya 808 (c), and Brevor (d).

Figure 1.

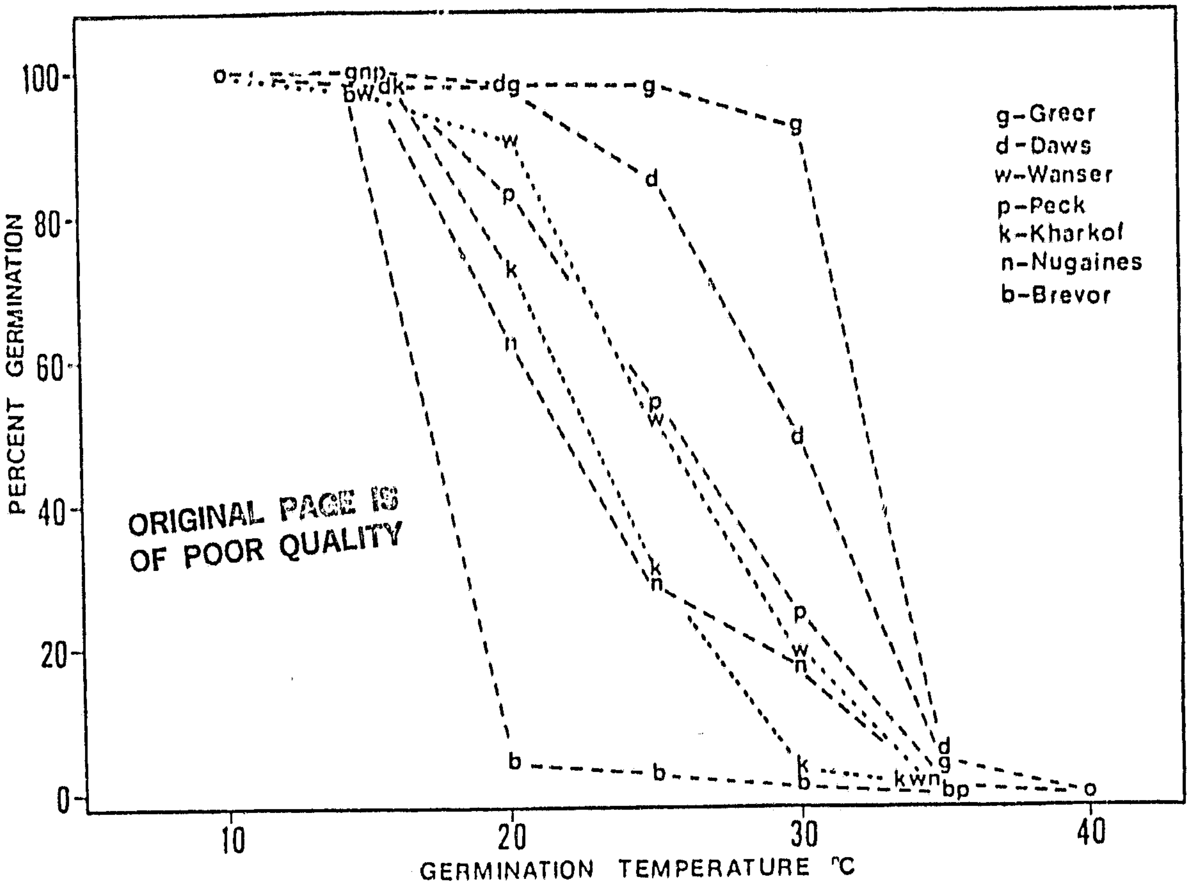


Figure 2.

POST-HARVEST DORMANCY OF WINTER WHEAT GERMINATED AT 30C

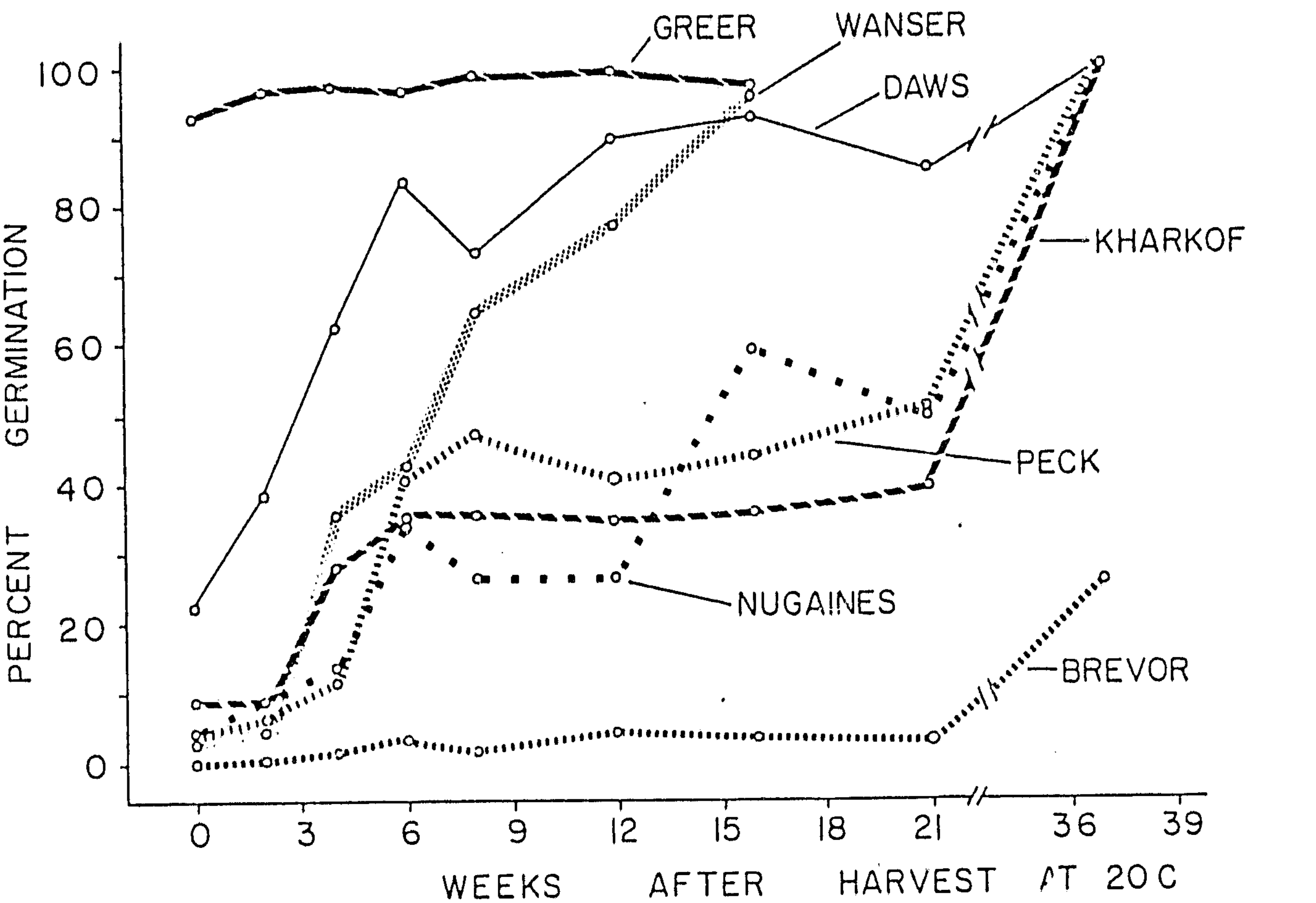


Figure 3.

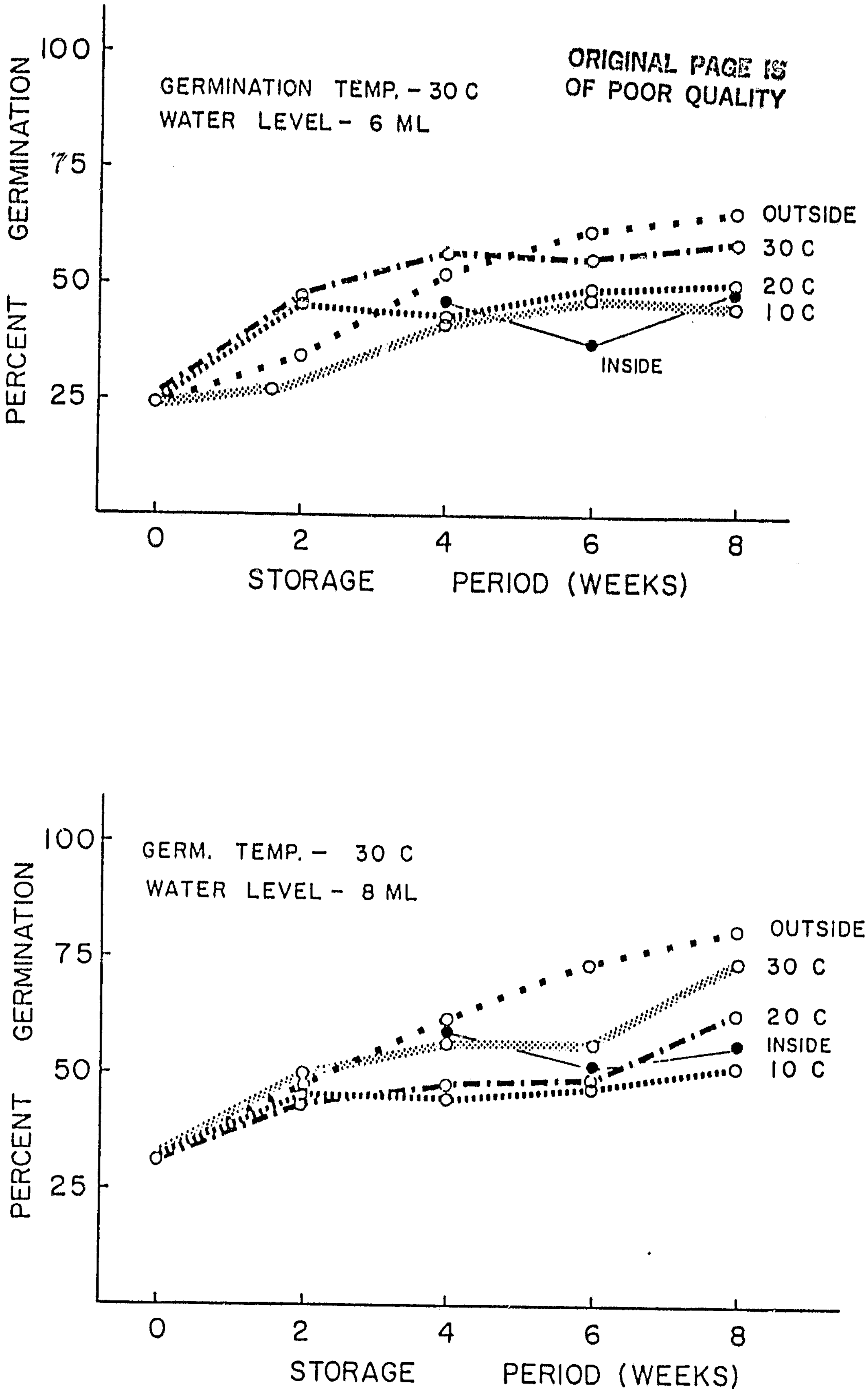

GERMINATION TEMP. - 30 C
WATER LEVEL - 6 ML
PERCENT GERMINATION
100
75
50
25
OUTSIDE
30 C
20 C
10 C
INSIDE
0
2
4
6
8
STORAGE PERIOD (WEEKS)
GERM. TEMP. - 30 C
WATER LEVEL - 8 ML
PERCENT GERMINATION
100
75
50
25
OUTSIDE
30 C
20 C
INSIDE
10 C
0
2
4
6
8
STORAGE PERIOD (WEEKS)

Figure 4.

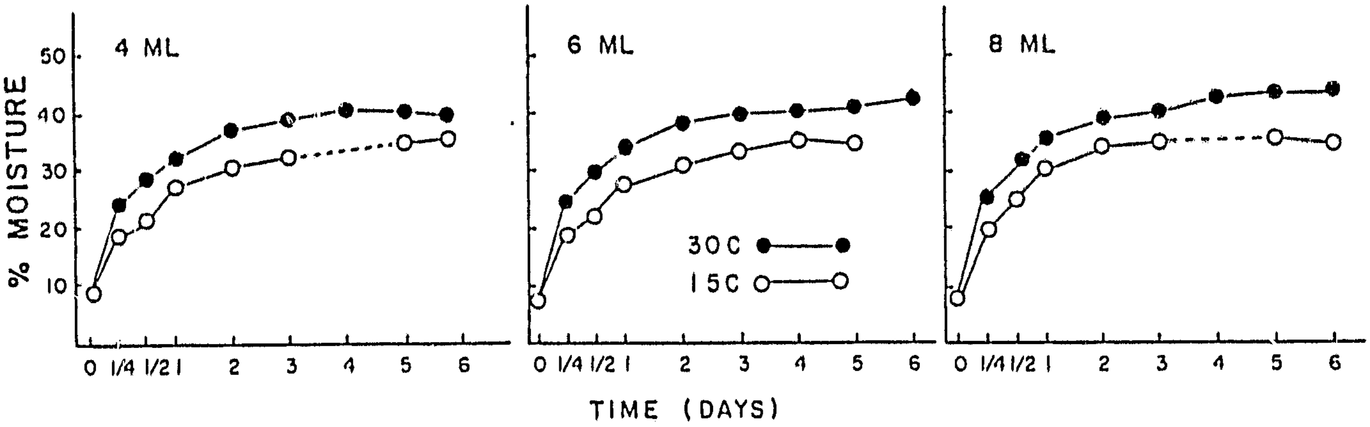


Figure 5.

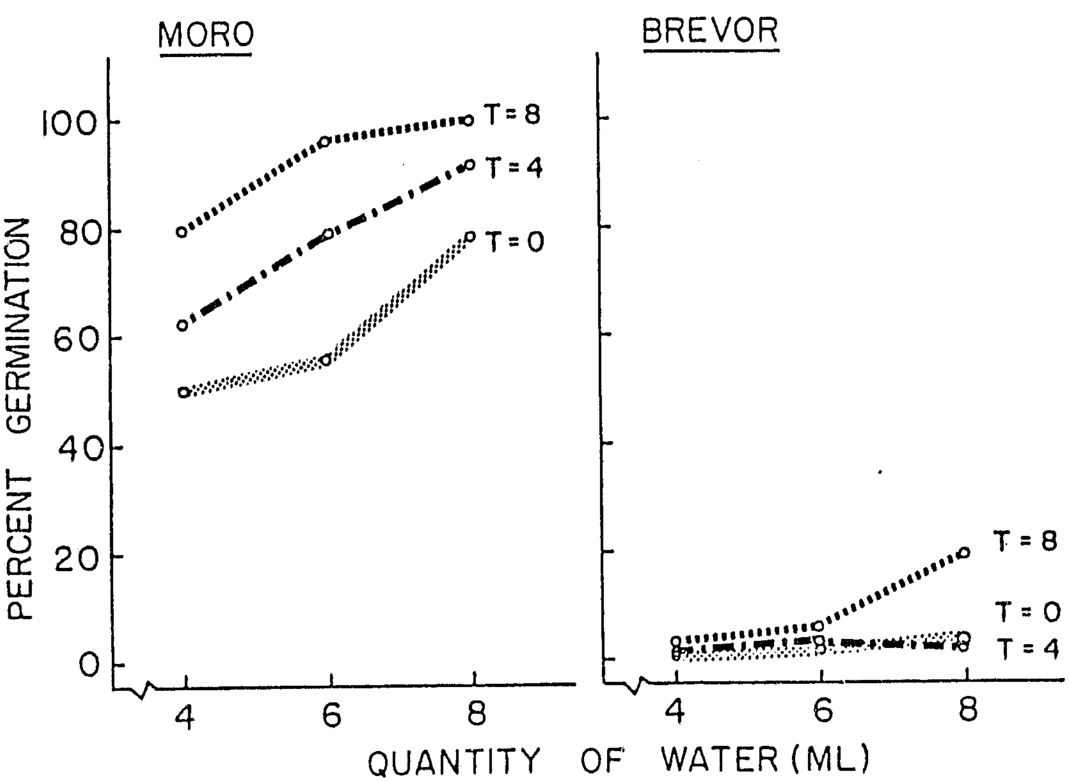
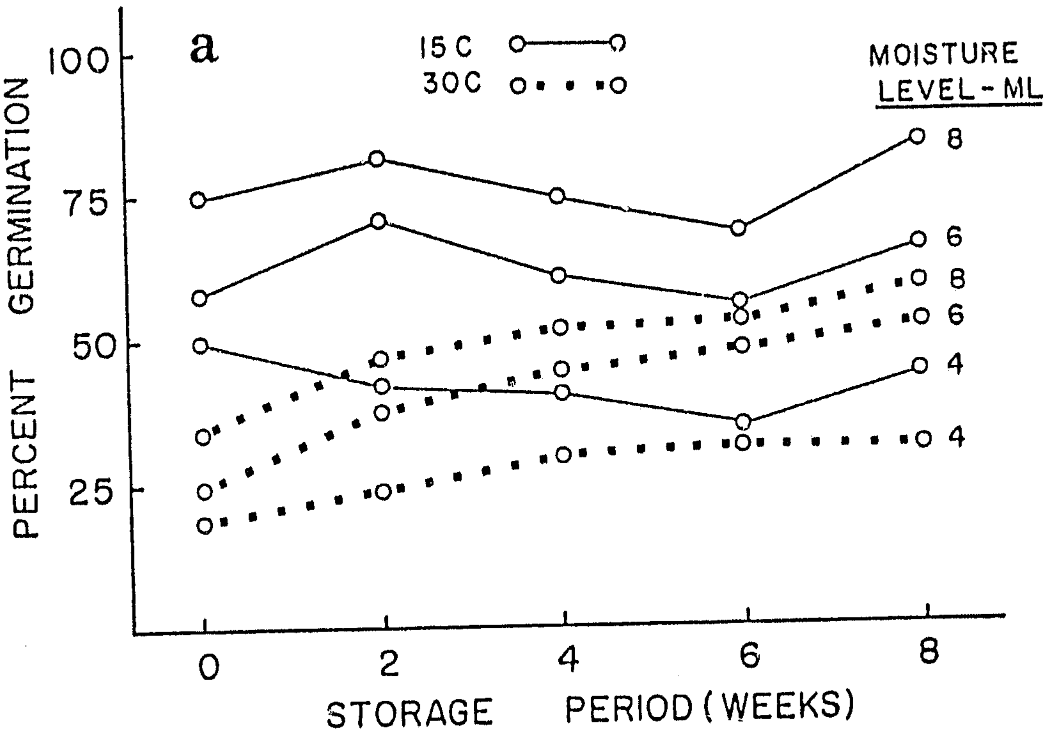


Figure 6.


a
15 C
30C
MOISTURE
LEVEL-ML
8
6
8
6
4
4
100
75
50
25
PERCENT GERMINATION
0
2
4
6
8
STORAGE PERIOD (WEEKS)

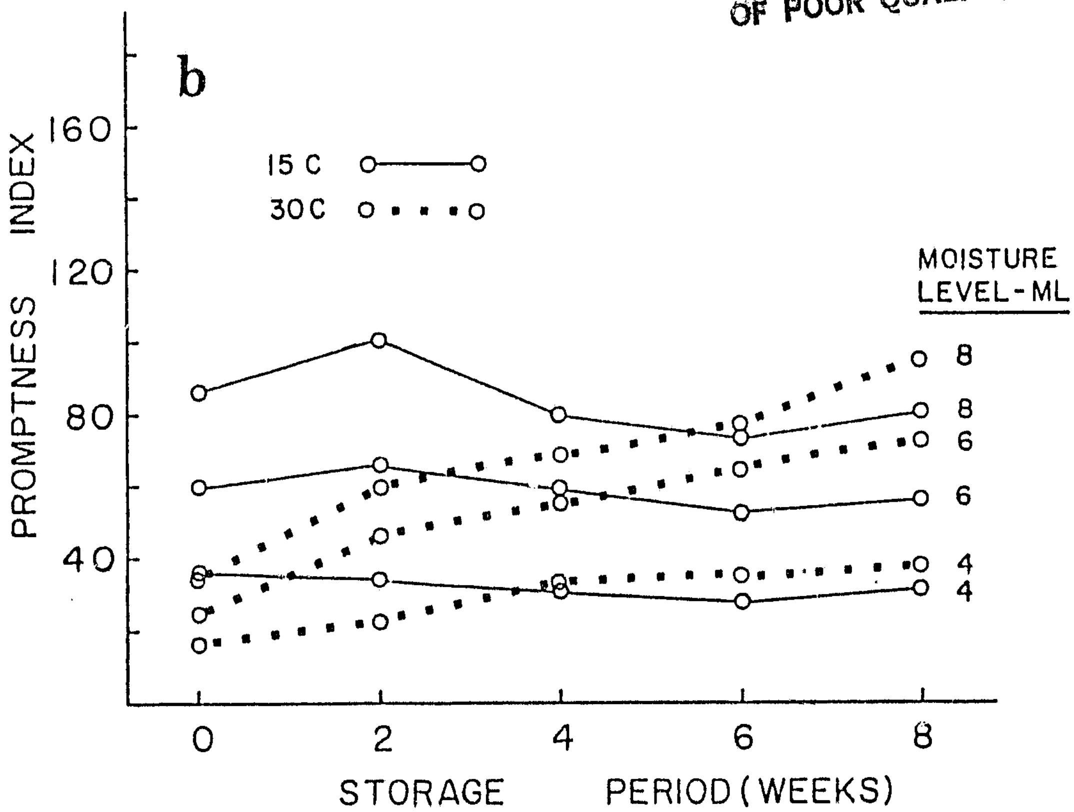

b
15 C
30C
MOISTURE
LEVEL-ML
8
8
6
6
4
4
160
120
80
40
PROMPTNESS INDEX
0
2
4
6
8
STORAGE PERIOD (WEEKS)

Figure 7.

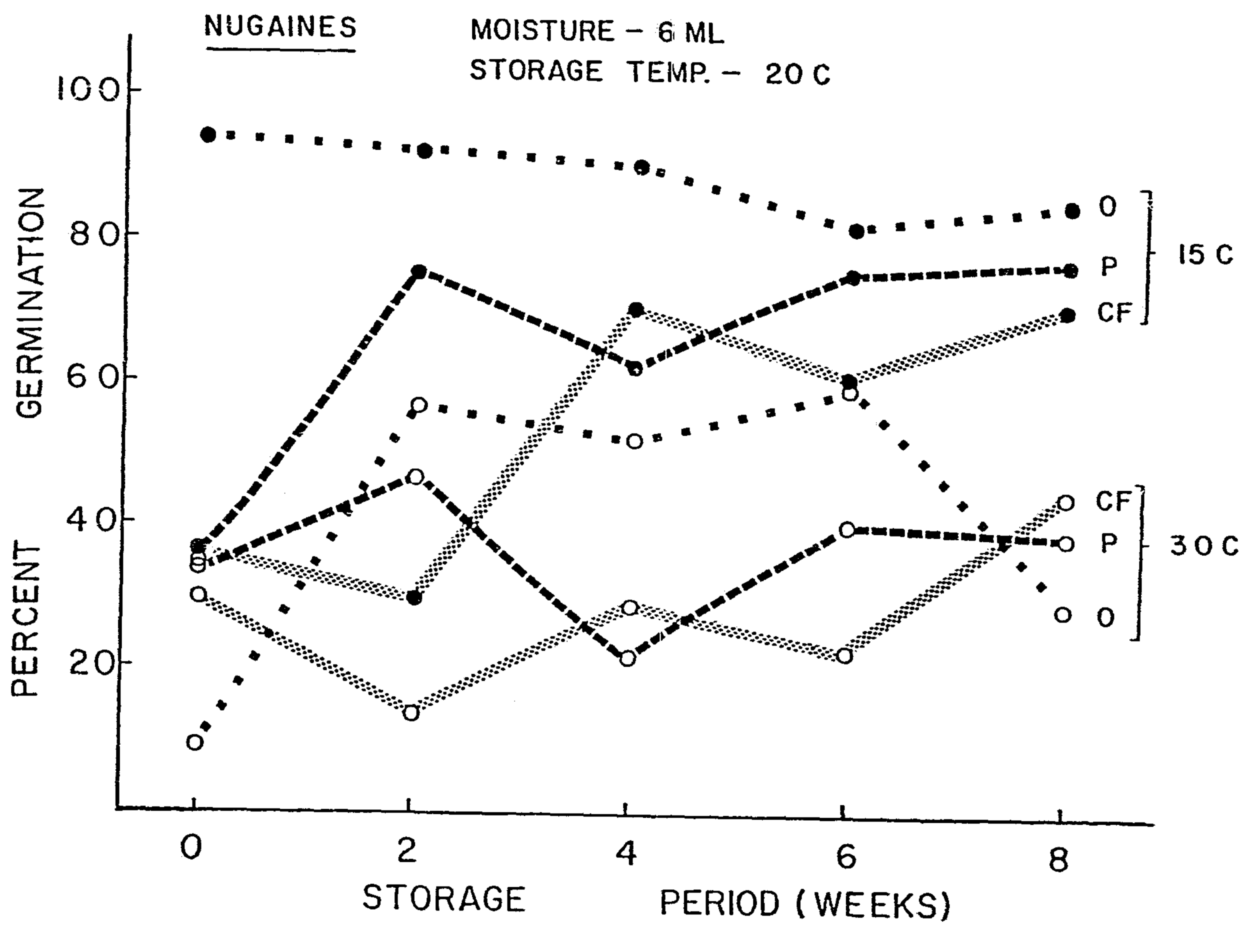


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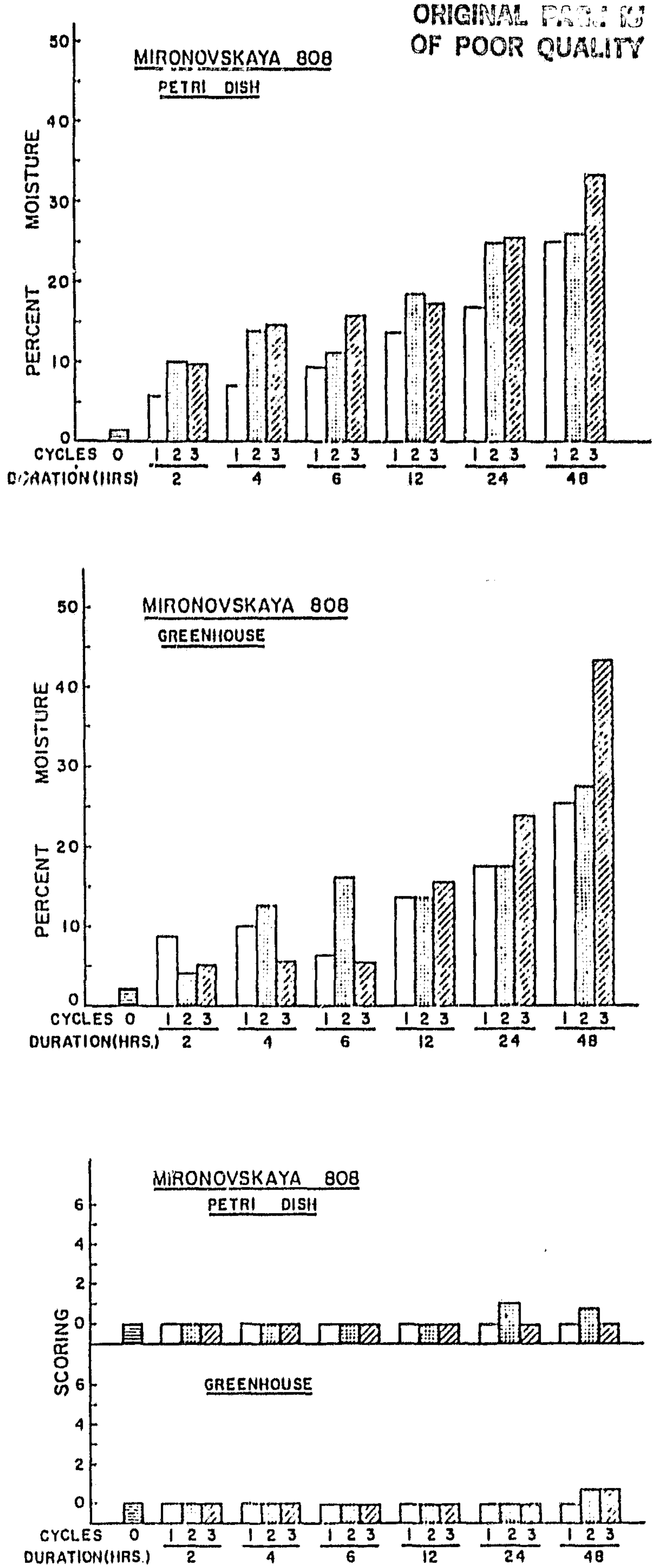
Figure 8a.


MIRONOVSKAYA 808
PETRI DISH
PERCENT MOISTURE
50
40
30
20
10
0
CYCLES 0 1 2 3 1 2 3 1 2 3 1 2 3 1 2 3 1 2 3
DURATION (HRS) 2 4 6 12 24 48
MIRONOVSKAYA 808
GREENHOUSE
PERCENT MOISTURE
50
40
30
20
10
0
CYCLES 0 1 2 3 1 2 3 1 2 3 1 2 3 1 2 3 1 2 3
DURATION(HRS.) 2 4 6 12 24 48
MIRONOVSKAYA 808
PETRI DISH
GREENHOUSE
SCORING
6
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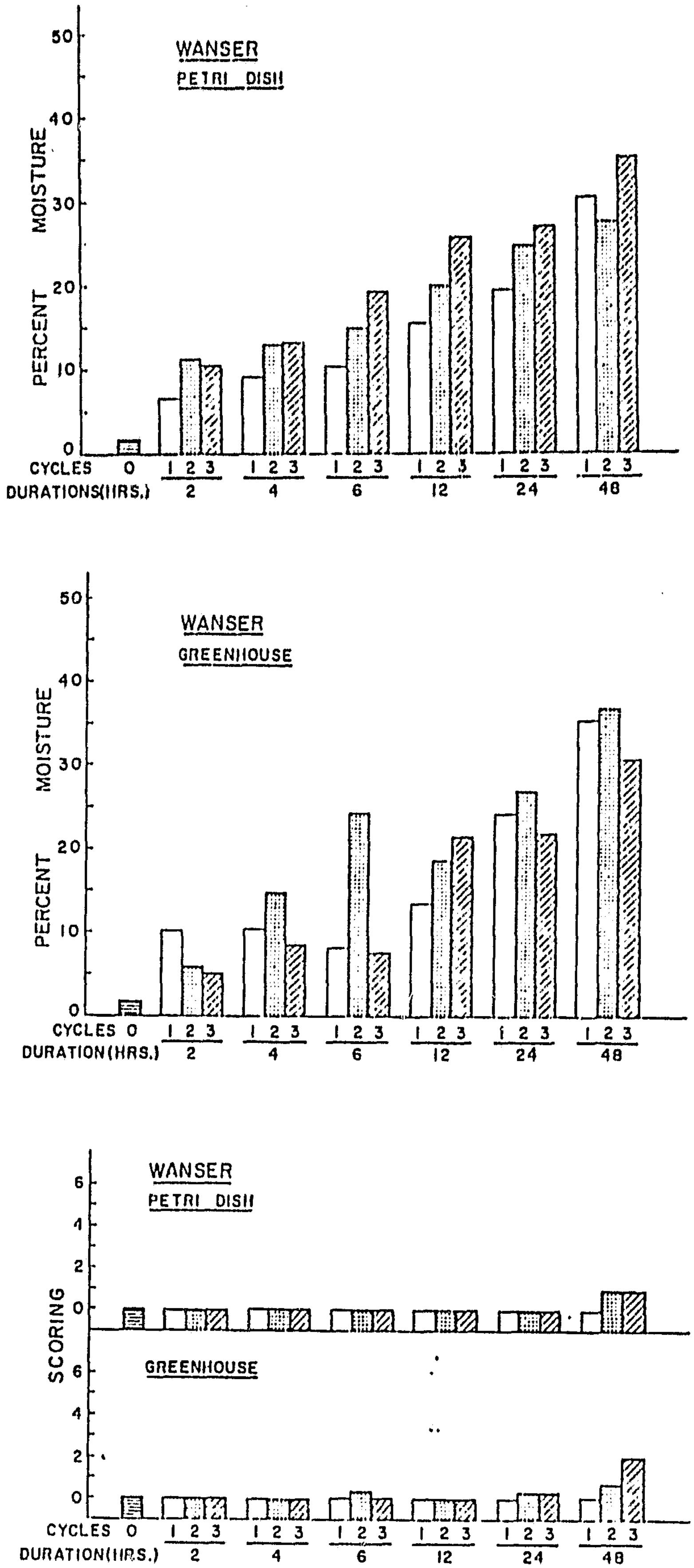
CYCLES 0 1 2 3 1 2 3 1 2 3 1 2 3 1 2 3 1 2 3
DURATION(HRS.) 2 4 6 12 24 48

Figure 8b.


WANSER
PETRI DISH
PERCENT MOISTURE
0
10
20
30
40
50
CYCLES 0 1 2 3 1 2 3 1 2 3 1 2 3 1 2 3 1 2 3
DURATIONS(HRS.) 2 4 6 12 24 48
WANSER
GREENHOUSE
PERCENT MOISTURE
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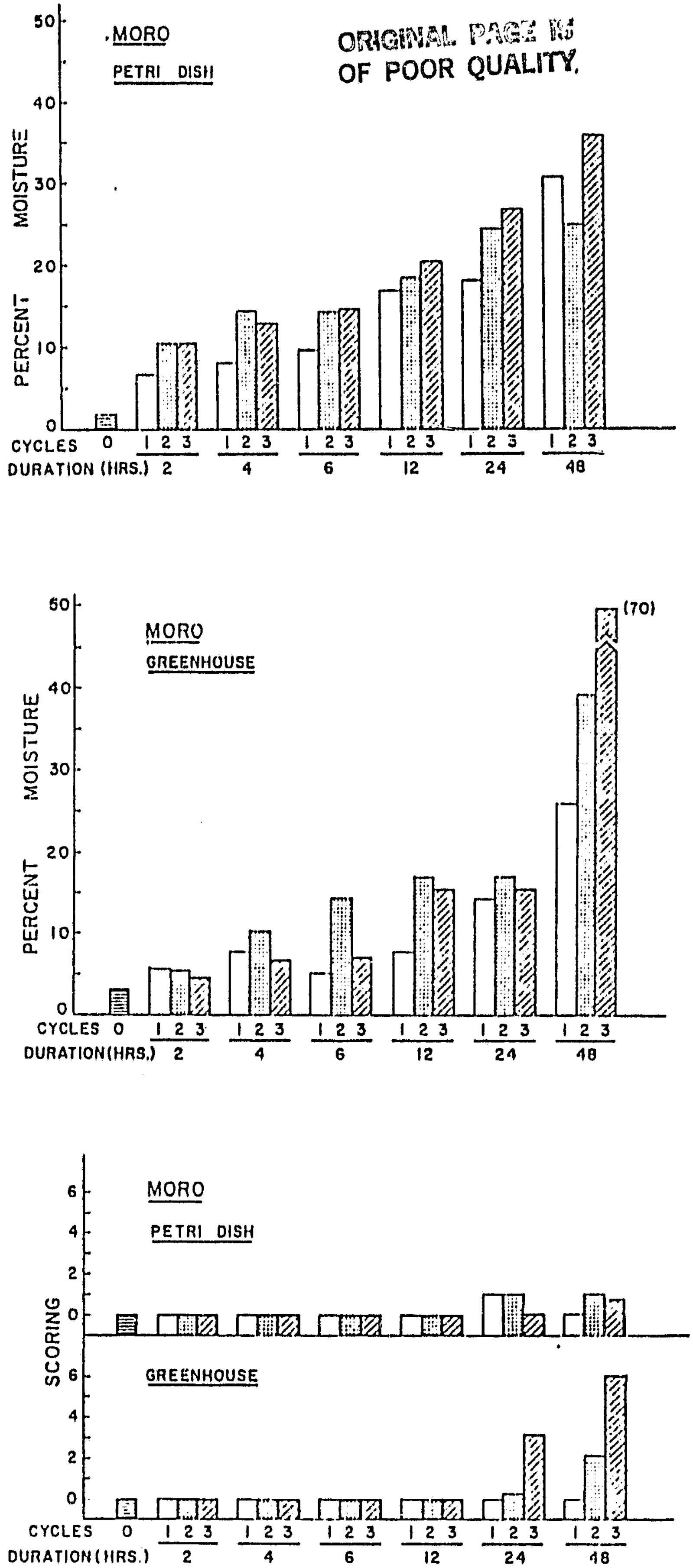
10
20
30
40
50
CYCLES 0 1 2 3 1 2 3 1 2 3 1 2 3 1 2 3 1 2 3
DURATION(HRS.) 2 4 6 12 24 48
WANSER
PETRI DISH
GREENHOUSE
SCORING
0
2
4
6
CYCLES 0 1 2 3 1 2 3 1 2 3 1 2 3 1 2 3 1 2 3
DURATION(HRS.) 2 4 6 12 24 48

Figure 8c.


MORO
PETRI DISH
PERCENT MOISTURE
50
40
30
20
10
0
CYCLES 0 1 2 3 1 2 3 1 2 3 1 2 3 1 2 3 1 2 3
DURATION (HRS.) 2 4 6 12 24 48
MORO
GREENHOUSE
(70)
PERCENT MOISTURE
50
40
30
20
10
0
CYCLES 0 1 2 3 1 2 3 1 2 3 1 2 3 1 2 3 1 2 3
DURATION (HRS.) 2 4 6 12 24 48
MORO
PETRI DISH
GREENHOUSE
SCORING
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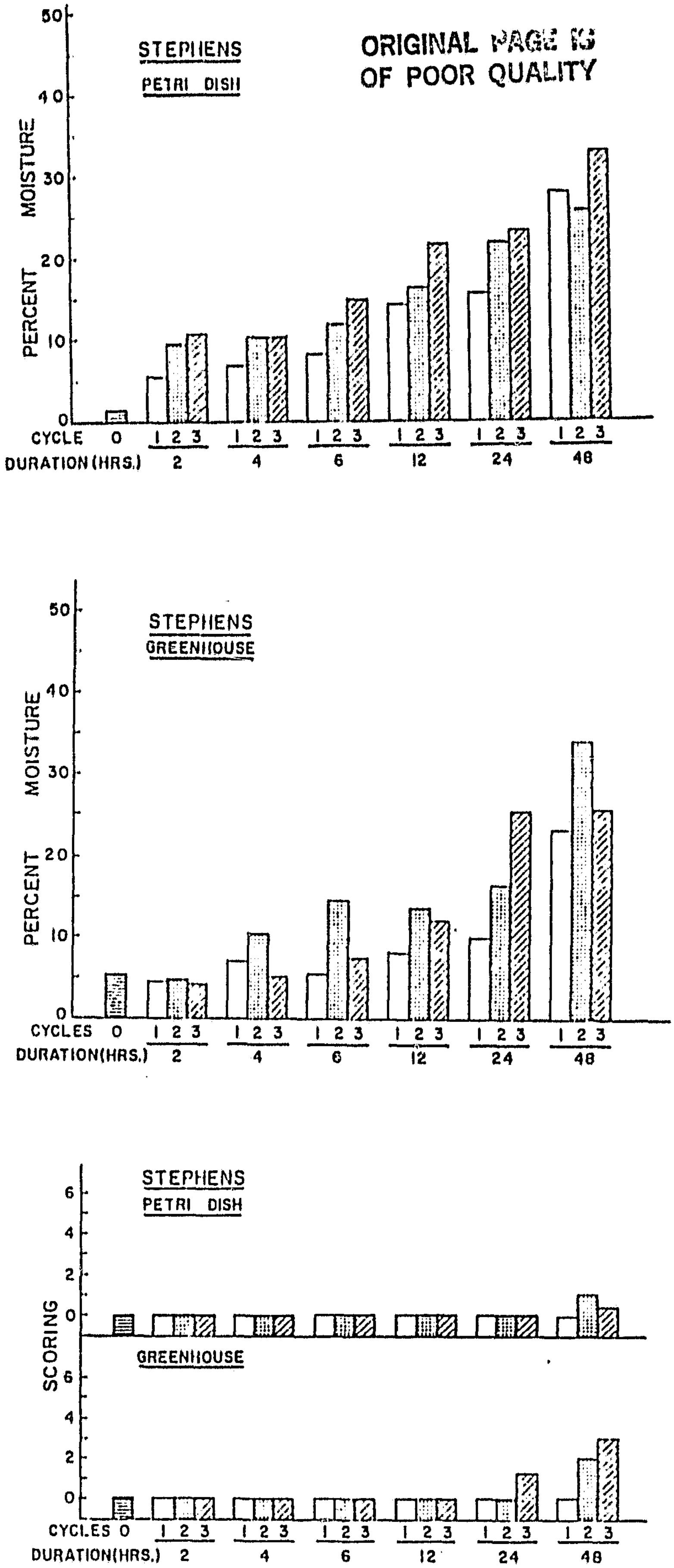
CYCLES 0 1 2 3 1 2 3 1 2 3 1 2 3 1 2 3 1 2 3
DURATION (HRS.) 2 4 6 12 24 48

Figure 8b.


STEPHENS
PETRI DISH
PERCENT MOISTURE
50
40
30
20
10
0
CYCLE 0 1 2 3 1 2 3 1 2 3 1 2 3 1 2 3 1 2 3
DURATION (HRS.) 2 4 6 12 24 48
STEPHENS
GREENHOUSE
PERCENT MOISTURE
50
40
30
20
10
0
CYCLES 0 1 2 3 1 2 3 1 2 3 1 2 3 1 2 3 1 2 3
DURATION (HRS.) 2 4 6 12 24 48
STEPHENS
PETRI DISH
GREENHOUSE
SCORING
6
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CYCLES 0 1 2 3 1 2 3 1 2 3 1 2 3 1 2 3 1 2 3
DURATION (HRS.) 2 4 6 12 24 48

Figure 5.

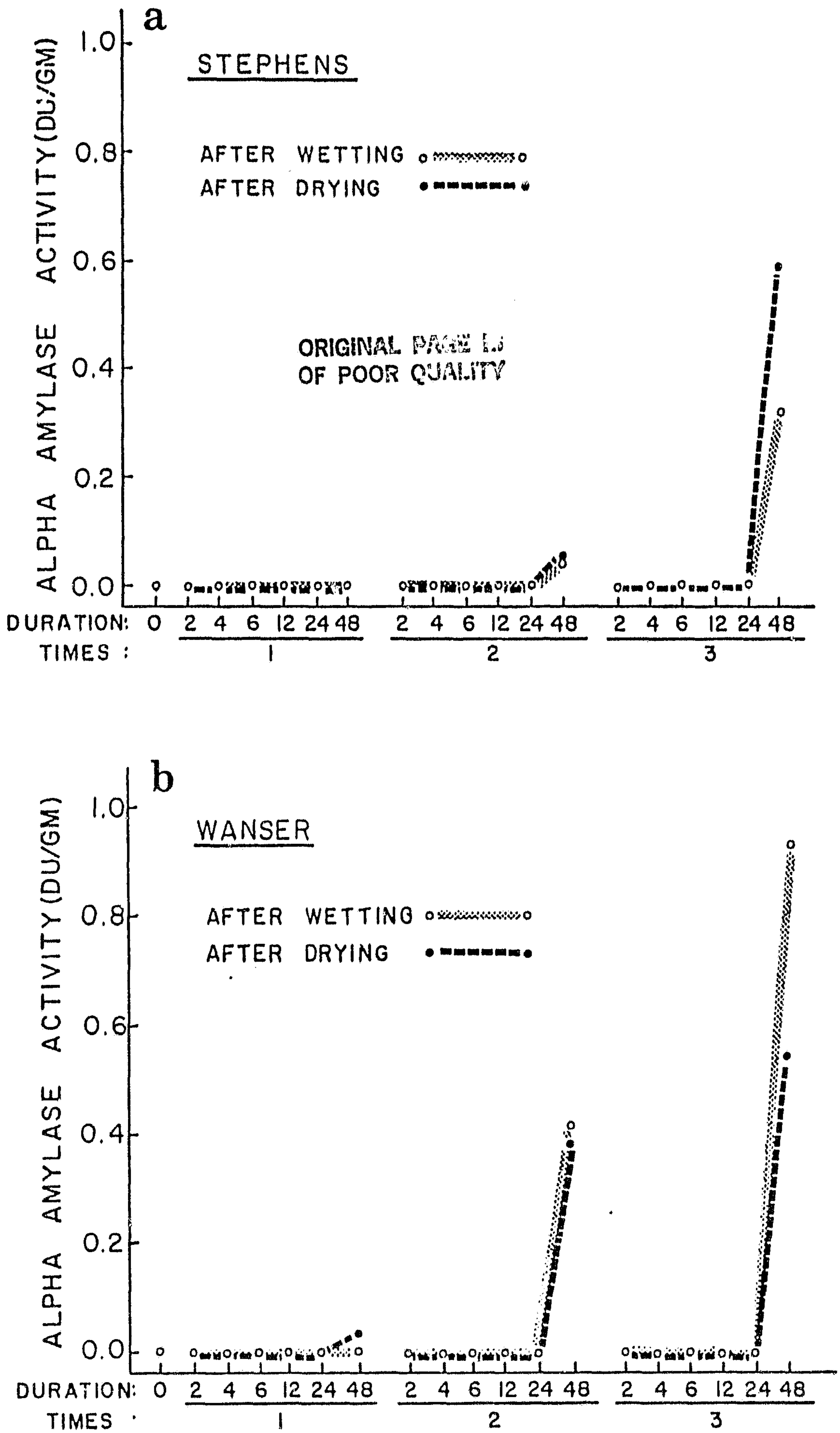
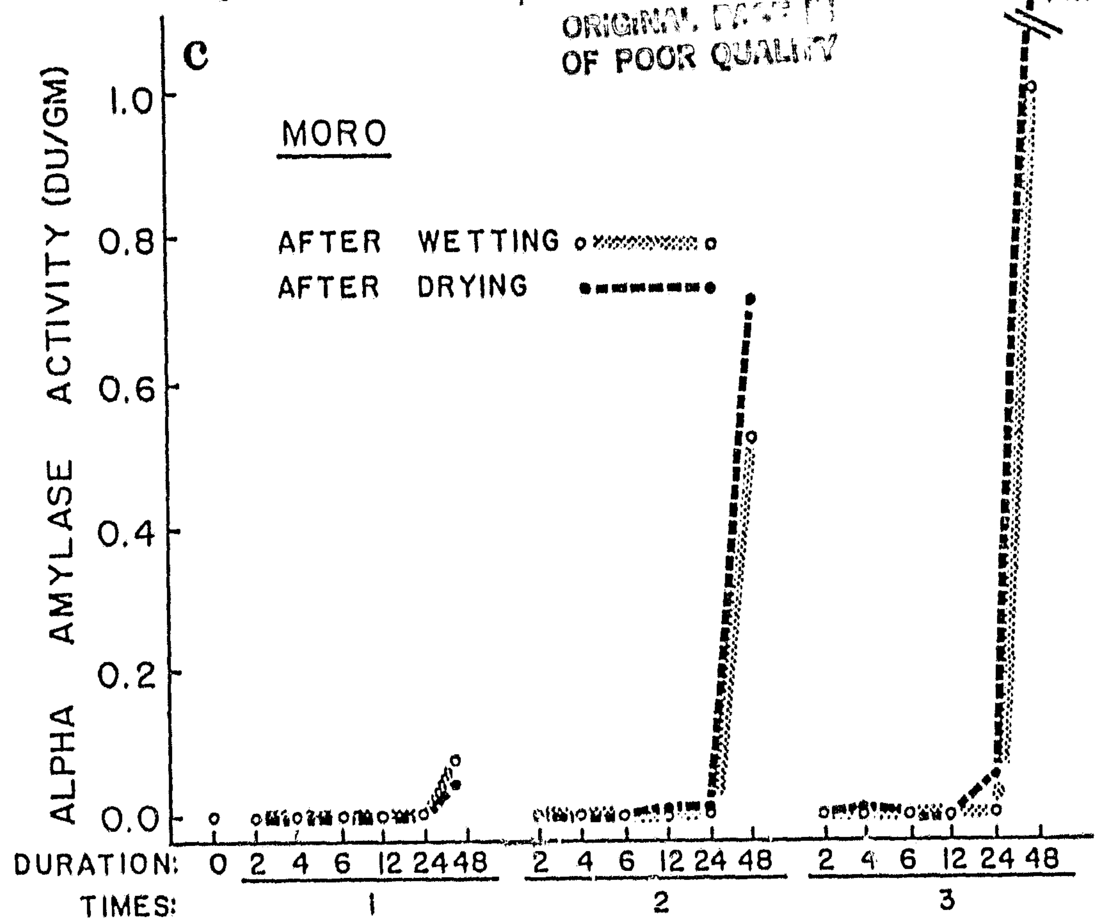

a
STEPHENS
ALPHA AMYLASE ACTIVITY (DU/GM)
1.0
0.8
0.6
0.4
0.2
0.0
AFTER WETTING
AFTER DRYING
ORIGINAL PAGE IS OF POOR QUALITY
DURATION: 0 2 4 6 12 24 48 2 4 6 12 24 48 2 4 6 12 24 48
TIMES : 1 2 3
b
WANSER
ALPHA AMYLASE ACTIVITY (DU/GM)
1.0
0.8
0.6
0.4
0.2
0.0
AFTER WETTING
AFTER DRYING
DURATION: 0 2 4 6 12 24 48 2 4 6 12 24 48 2 4 6 12 24 48
TIMES : 1 2 3

Figure 9.


c
MORO
AFTER WETTING
AFTER DRYING
ALPHA AMYLASE ACTIVITY (DU/GM)
1.0
0.8
0.6
0.4
0.2
0.0
(4.75)
DURATION: 0 2 4 6 12 24 48 2 4 6 12 24 48 2 4 6 12 24 48
TIMES: 1 2 3

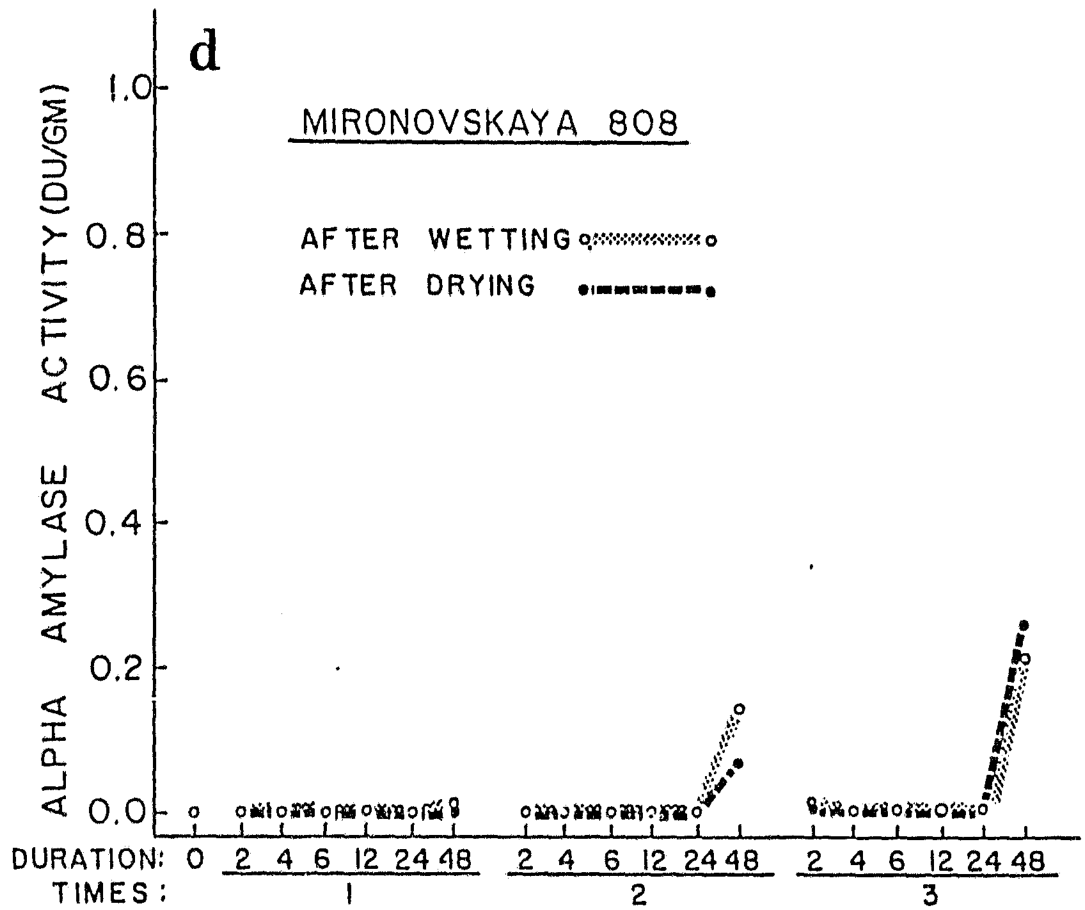

d
MIRONOVSKAYA 808
AFTER WETTING
AFTER DRYING
ALPHA AMYLASE ACTIVITY (DU/GM)
1.0
0.8
0.6
0.4
0.2
0.0
DURATION: 0 2 4 6 12 24 48 2 4 6 12 24 48 2 4 6 12 24 48
TIMES: 1 2 3

Figure 10a.

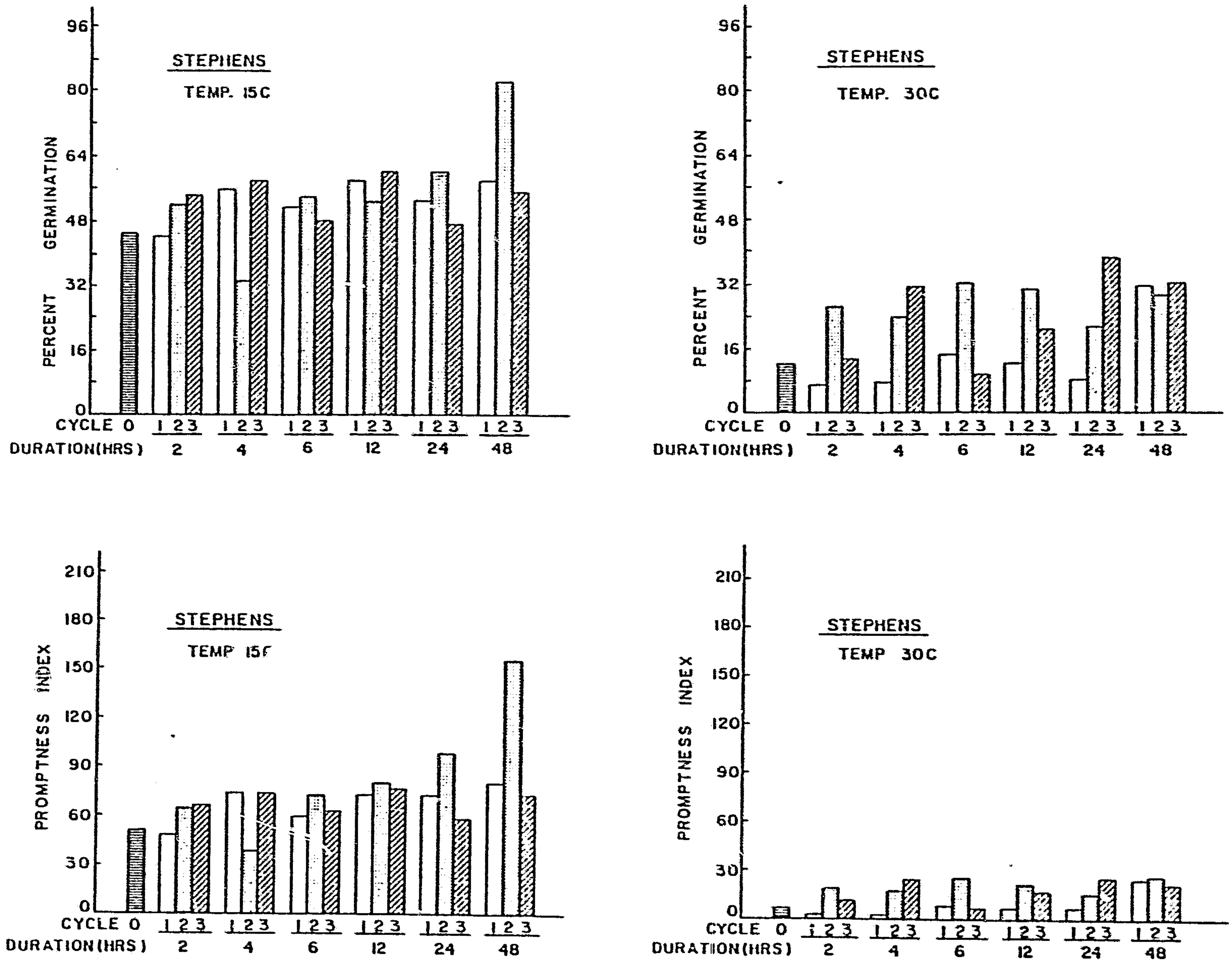

STEPHENS
TEMP. 15C
PERCENT GERMINATION
96
80
64
48
32
16
0
CYCLE 0 1 2 3 1 2 3 1 2 3 1 2 3 1 2 3 1 2 3
DURATION(HRS) 2 4 6 12 24 48
STEPHENS
TEMP. 30C
PERCENT GERMINATION
STEPHENS
TEMP 15C
PROMPTNESS INDEX
210
180
150
120
90
60
30
0
STEPHENS
TEMP 30C
PROMPTNESS INDEX

Figure 10b.

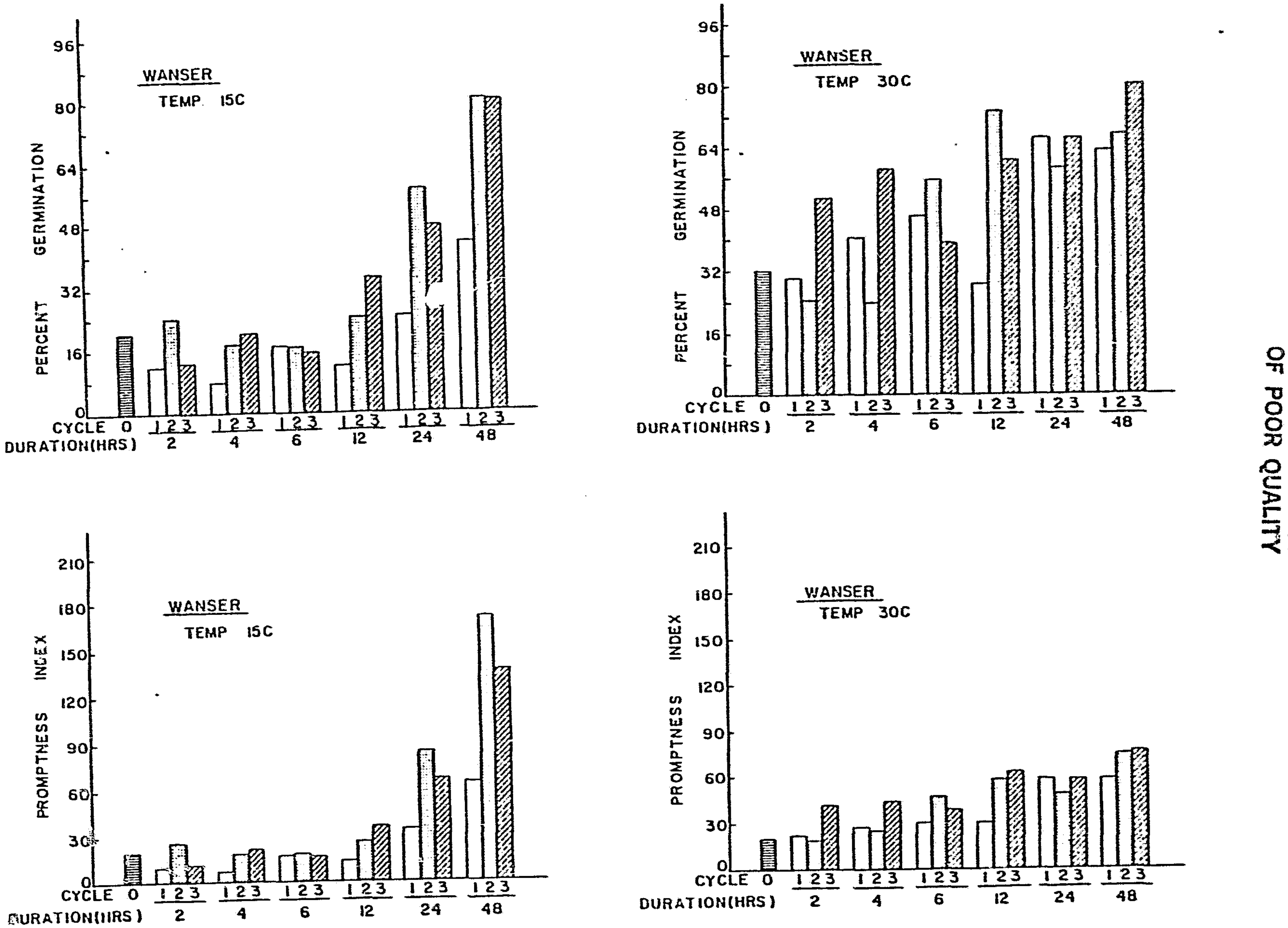


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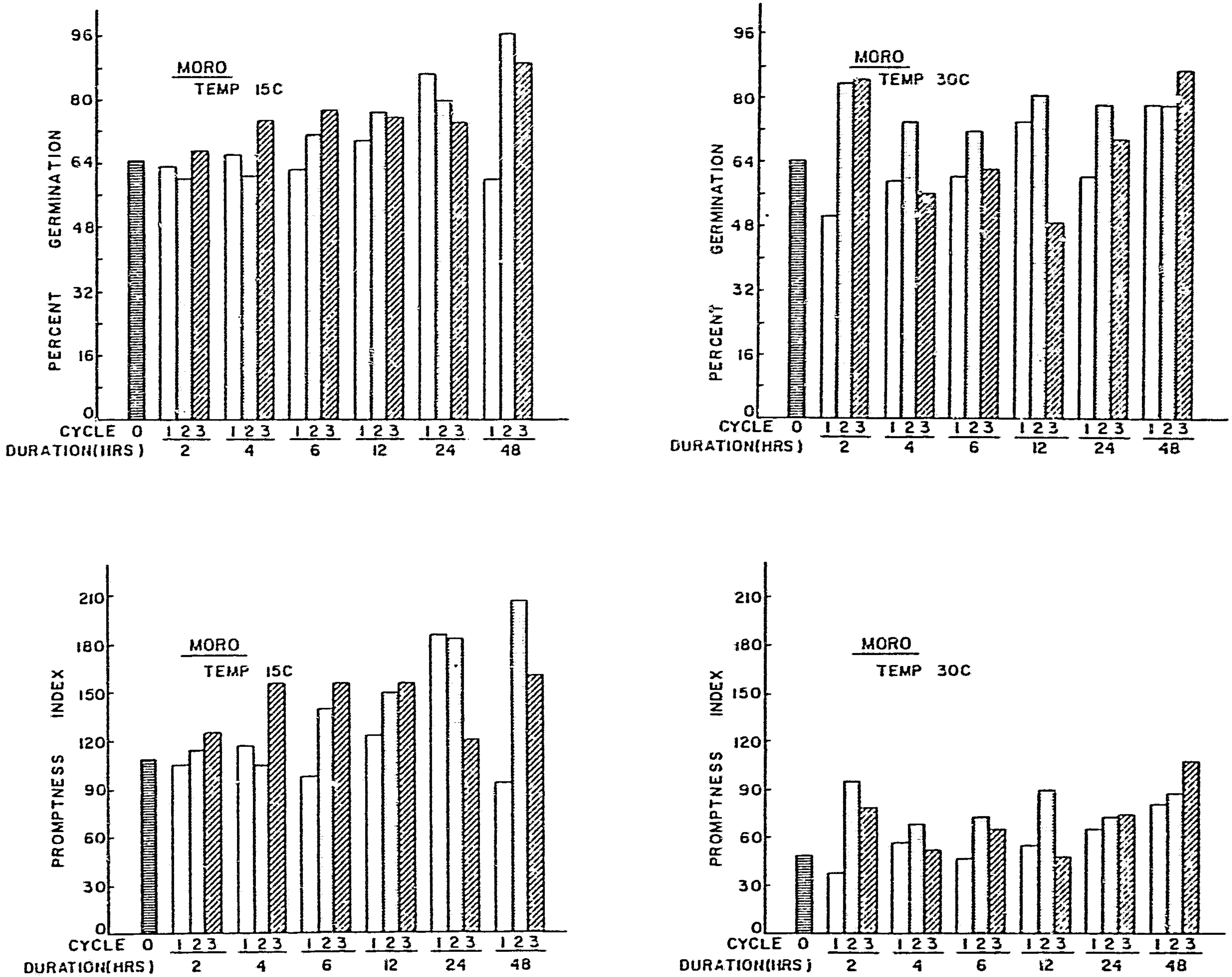
Figure 10c.



MORO
TEMP 15C
PERCENT GERMINATION
96
80
64
48
32
16
0
CYCLE 0 1 2 3 1 2 3 1 2 3 1 2 3 1 2 3 1 2 3
DURATION(HRS) 2 4 6 12 24 48
MORO
TEMP 30C
PERCENT GERMINATION
CYCLE 0 1 2 3 1 2 3 1 2 3 1 2 3 1 2 3 1 2 3
DURATION(HRS) 2 4 6 12 24 48
MORO
TEMP 15C
PROMPTNESS INDEX
210
180
150
120
90
60
30
0
CYCLE 0 1 2 3 1 2 3 1 2 3 1 2 3 1 2 3 1 2 3
DURATION(HRS) 2 4 6 12 24 48
MORO
TEMP 30C
PROMPTNESS INDEX
CYCLE 0 1 2 3 1 2 3 1 2 3 1 2 3 1 2 3 1 2 3
DURATION(HRS) 2 4 6 12 24 48

Figure 10d.

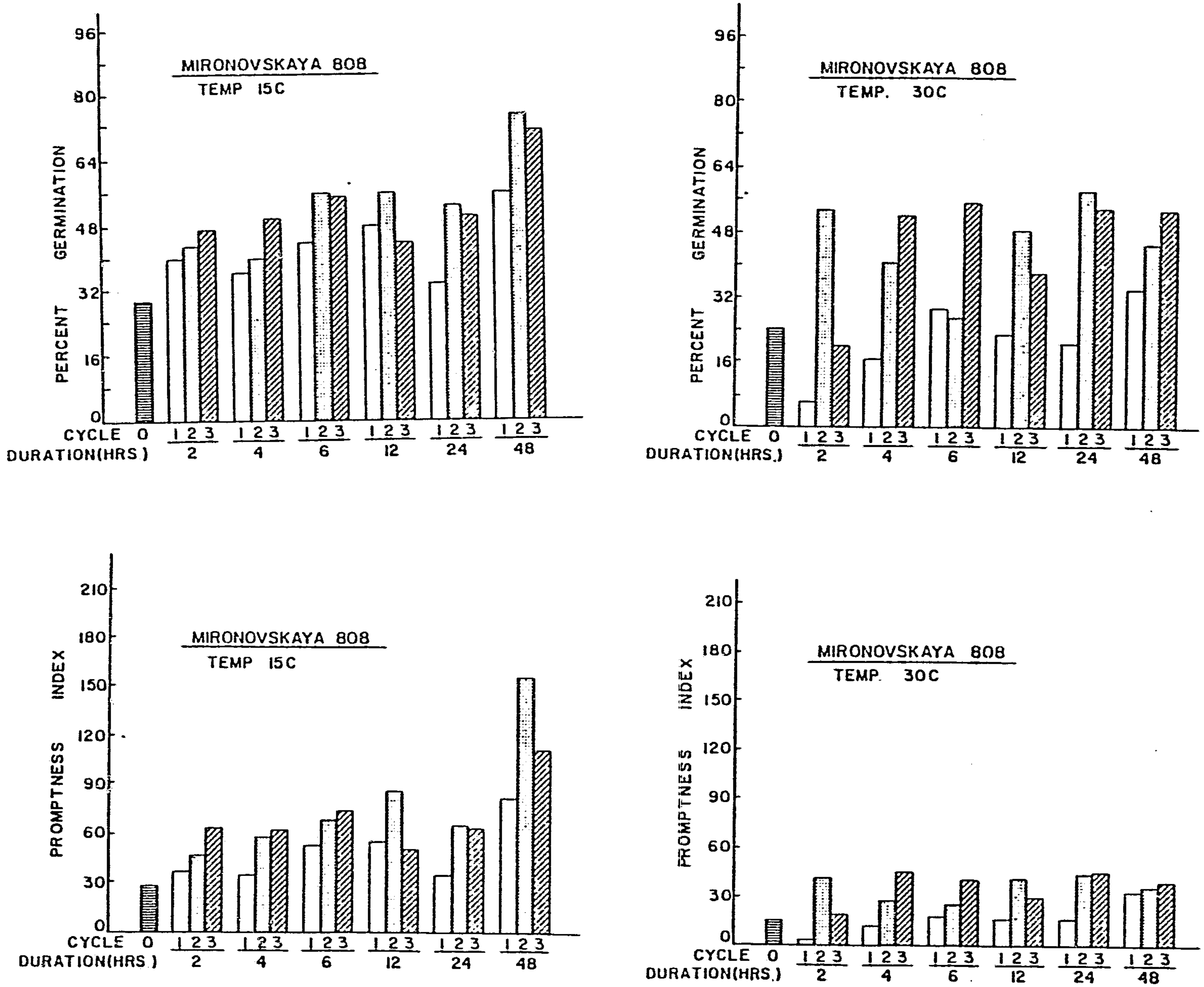
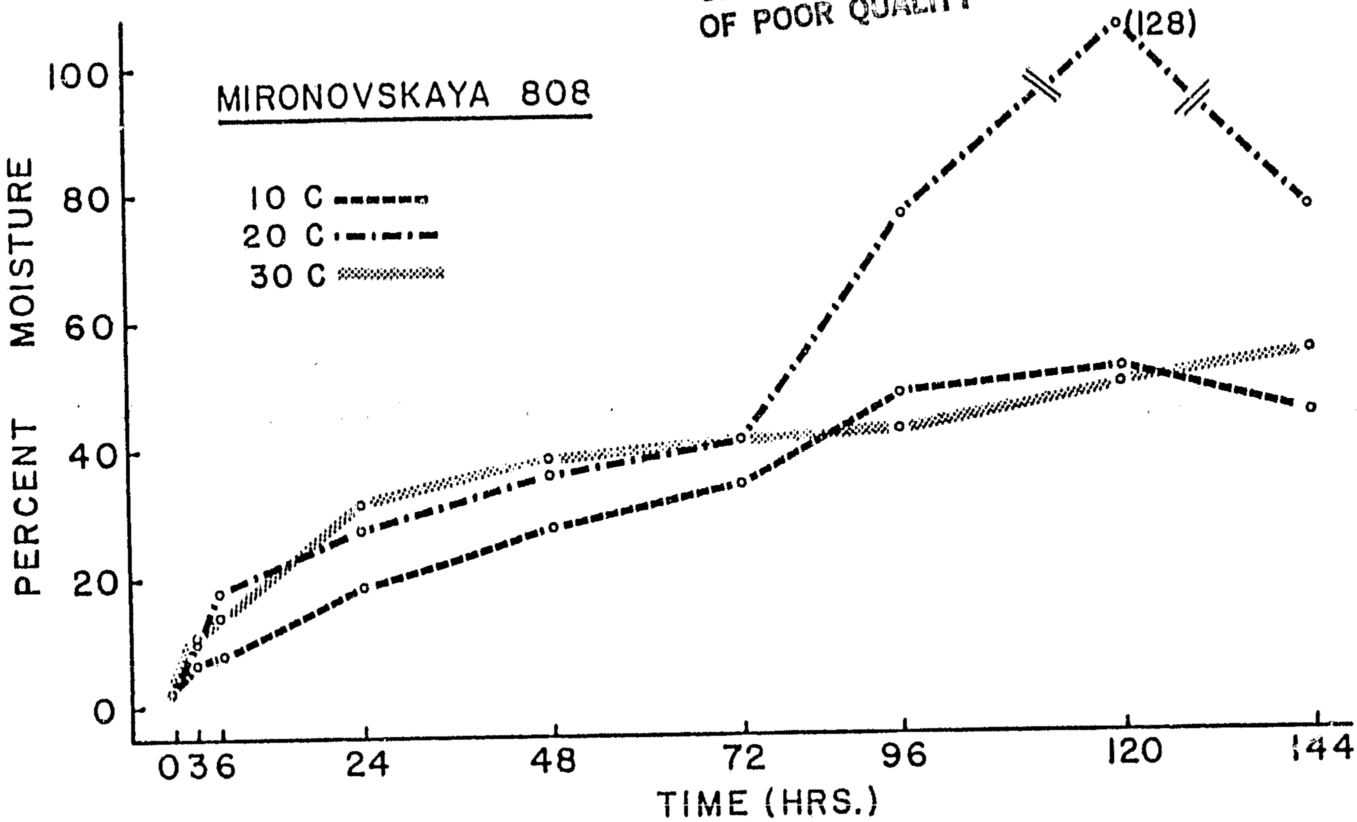

MIRONOVSKAYA 808
TEMP 15C
PERCENT GERMINATION
CYCLE
DURATION(HRS)
MIRONOVSKAYA 808
TEMP. 30C
PERCENT GERMINATION
CYCLE
DURATION(HRS.)
MIRONOVSKAYA 808
TEMP 15C
PROMPTNESS INDEX
CYCLE
DURATION(HRS)
MIRONOVSKAYA 808
TEMP. 30C
PROMPTNESS INDEX
CYCLE
DURATION(HRS.)

Figure 11a.


MIRONOVSKAYA 808
10 C
20 C
30 C
PERCENT MOISTURE
TIME (HRS.)
(128)
0
20
40
60
80
100
0 3 6
24
48
72
96
120
144

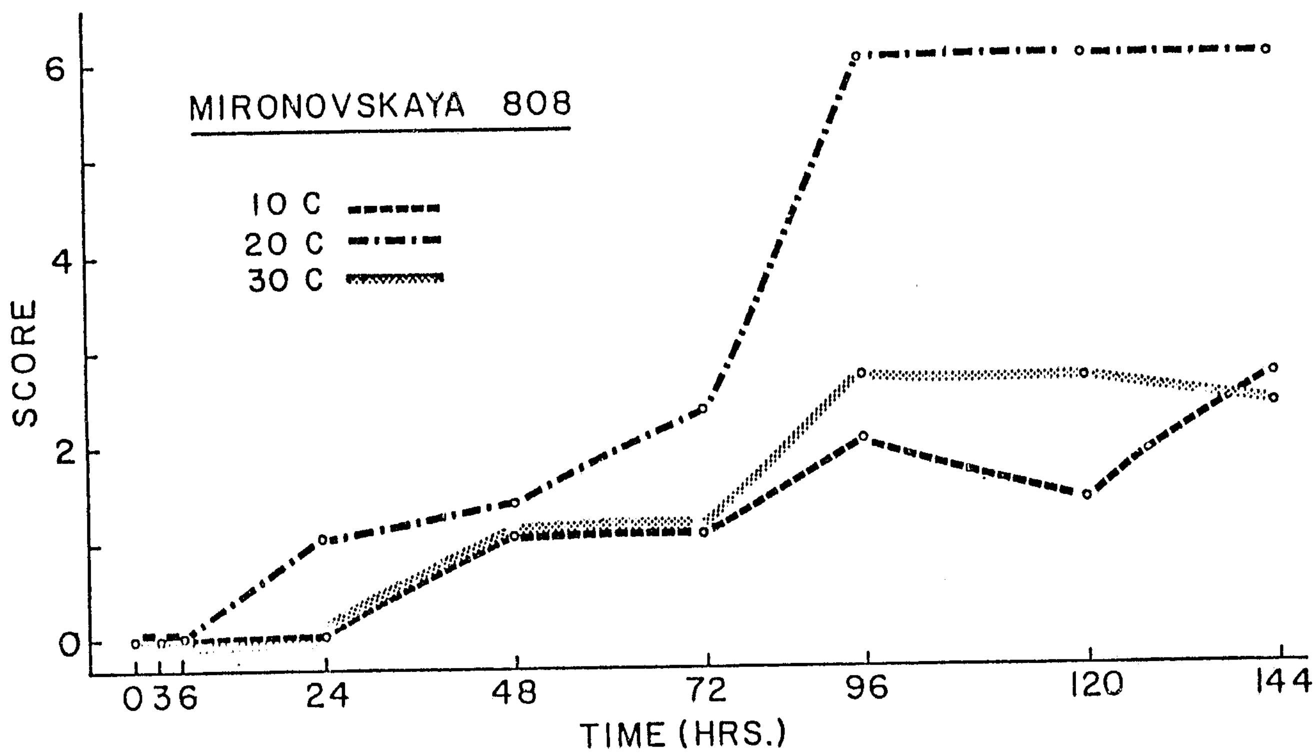
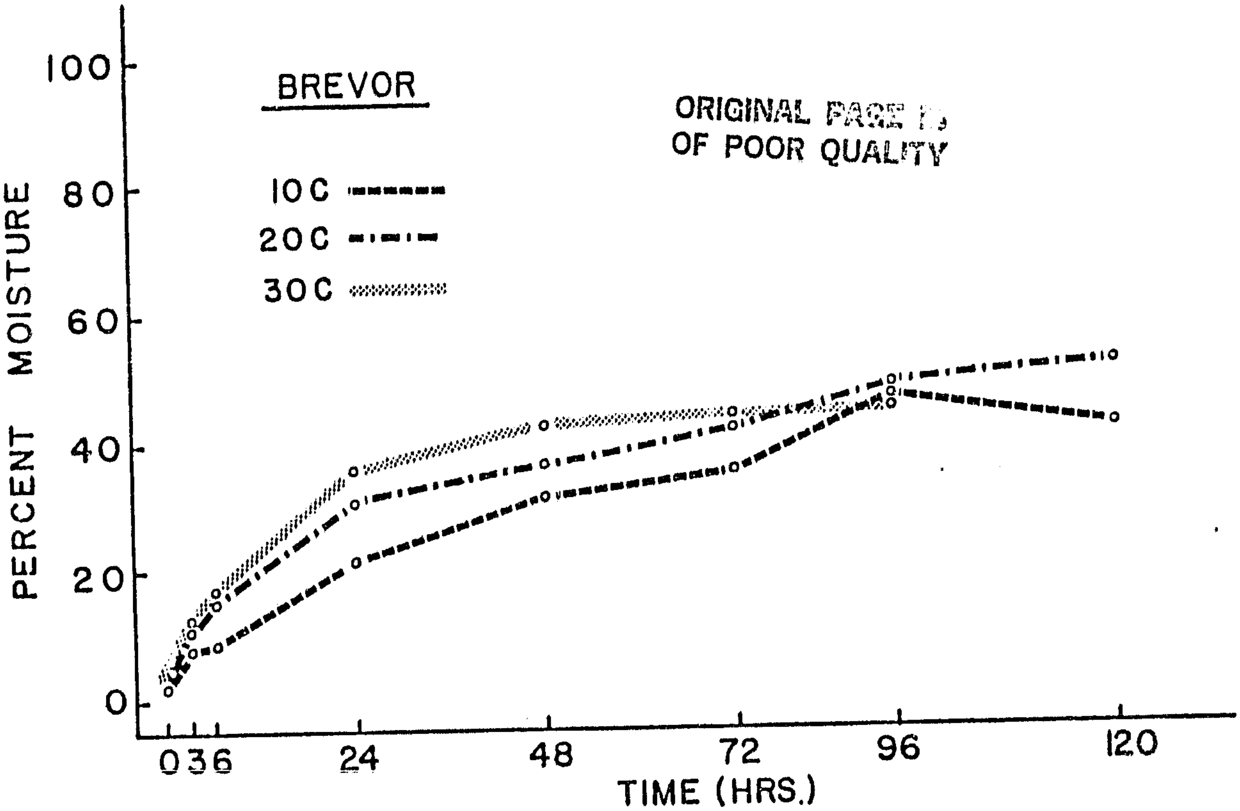

MIRONOVSKAYA 808
10 C
20 C
30 C
SCORE
TIME (HRS.)
0
2
4
6
0 3 6
24
48
72
96
120
144

Figure 11b.


BREVOR
10C
20C
30C
PERCENT MOISTURE
100
80
60
40
20
0
0 3 6
24
48
72
96
120
TIME (HRS.)

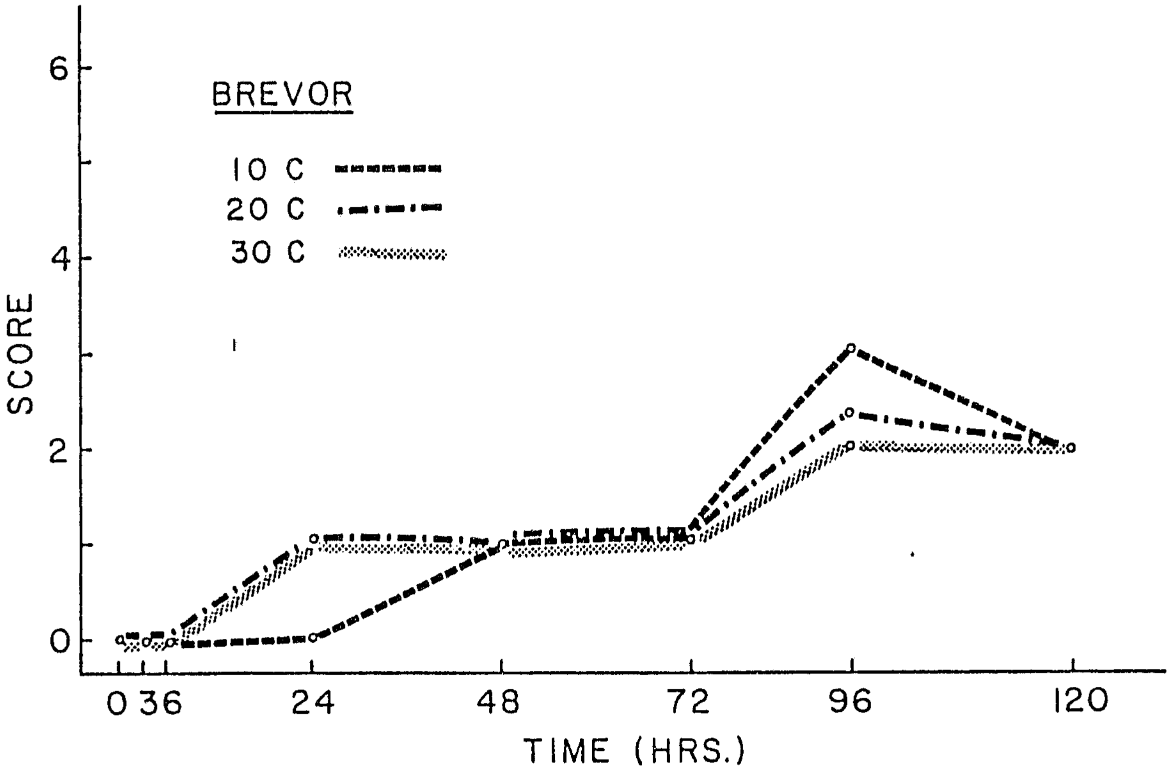

BREVOR
10 C
20 C
30 C
SCORE
6
4
2
0
0 3 6
24
48
72
96
120
TIME (HRS.)

Figure 11c.

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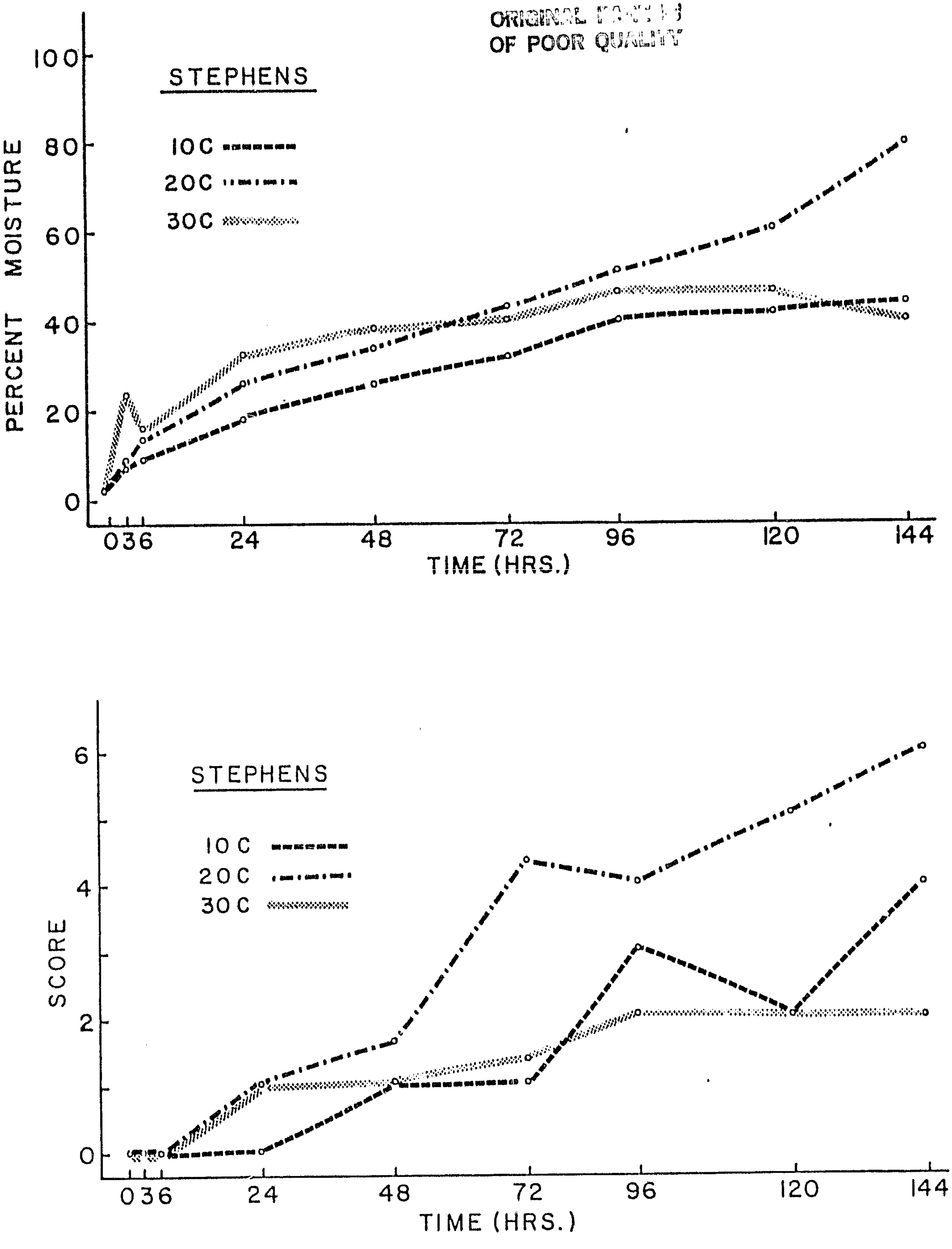
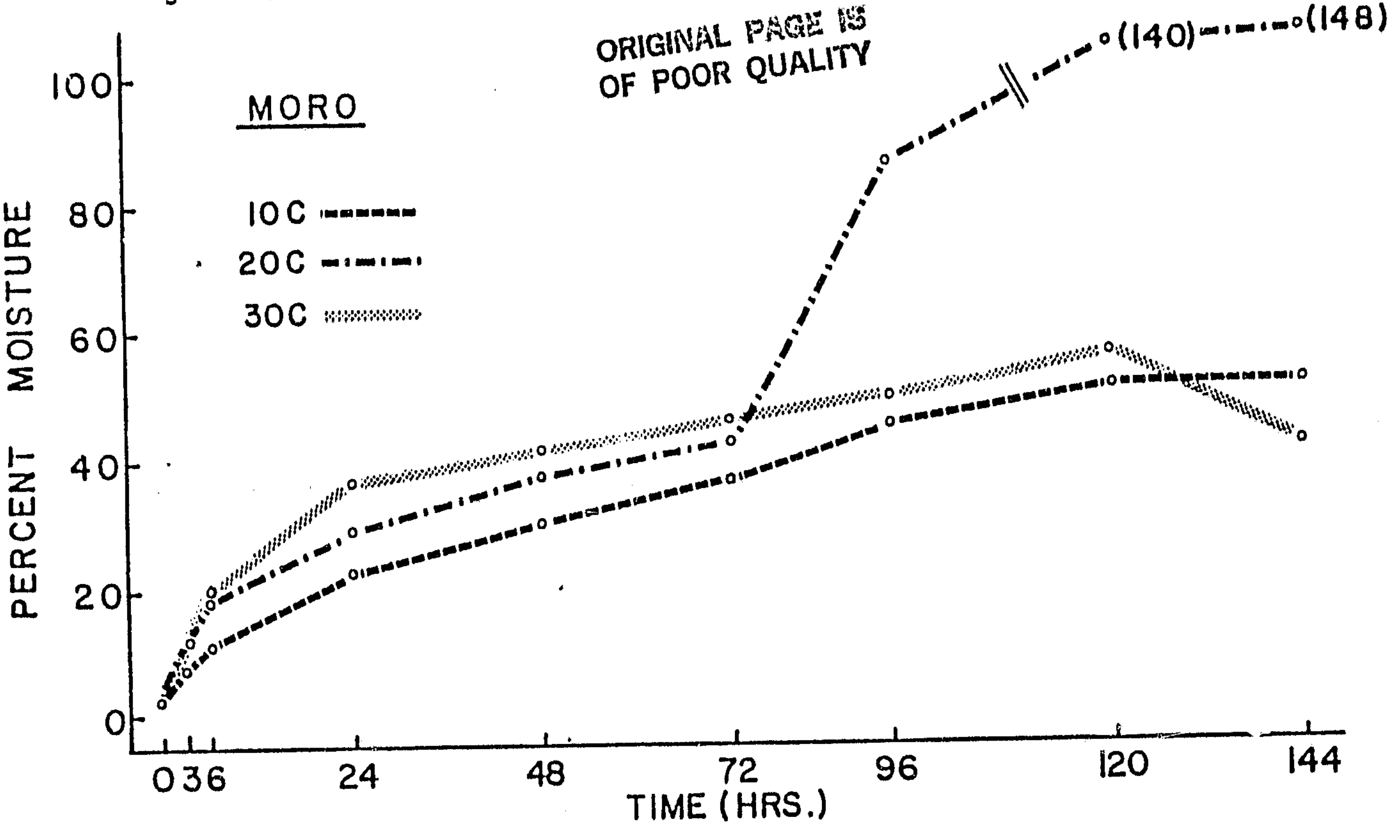


Figure 11d.


MORO
10C
20C
30C
(140)
(148)
PERCENT MOISTURE
0
20
40
60
80
100
0 3 6
24
48
72
96
120
144
TIME (HRS.)

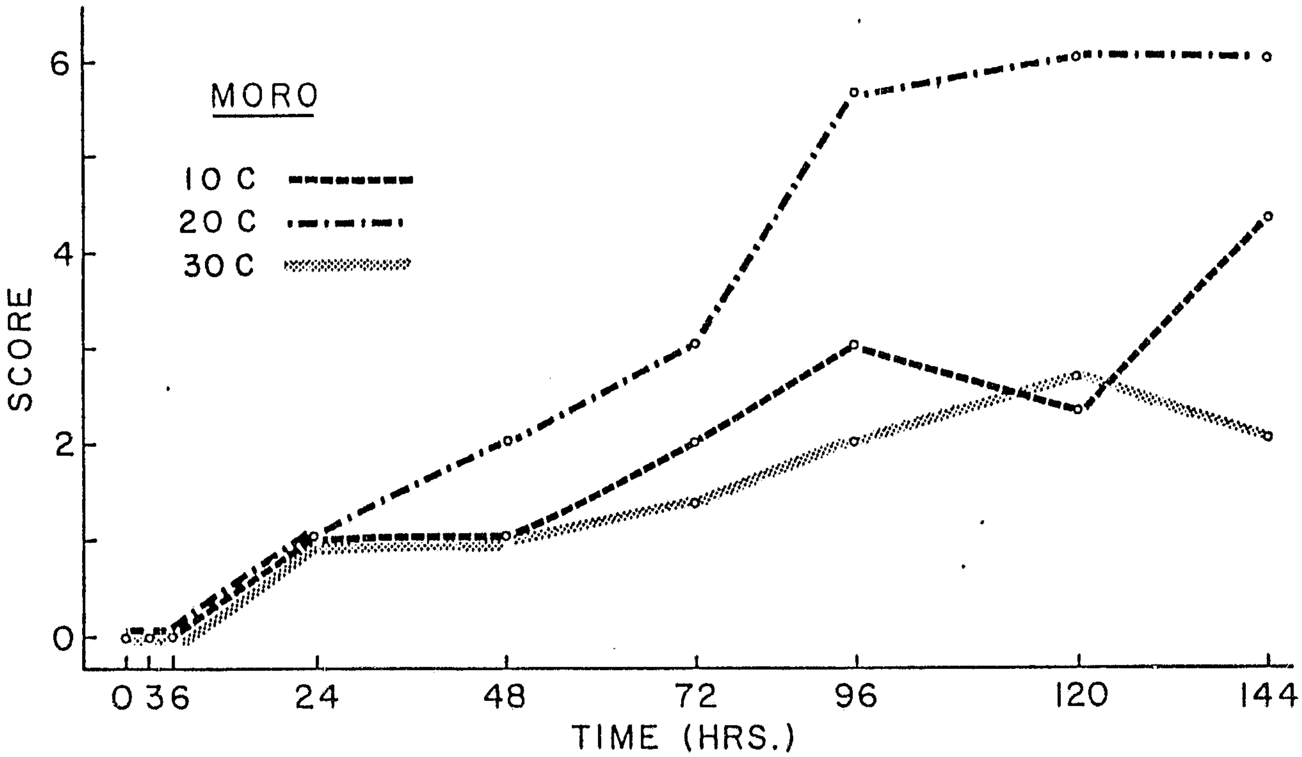
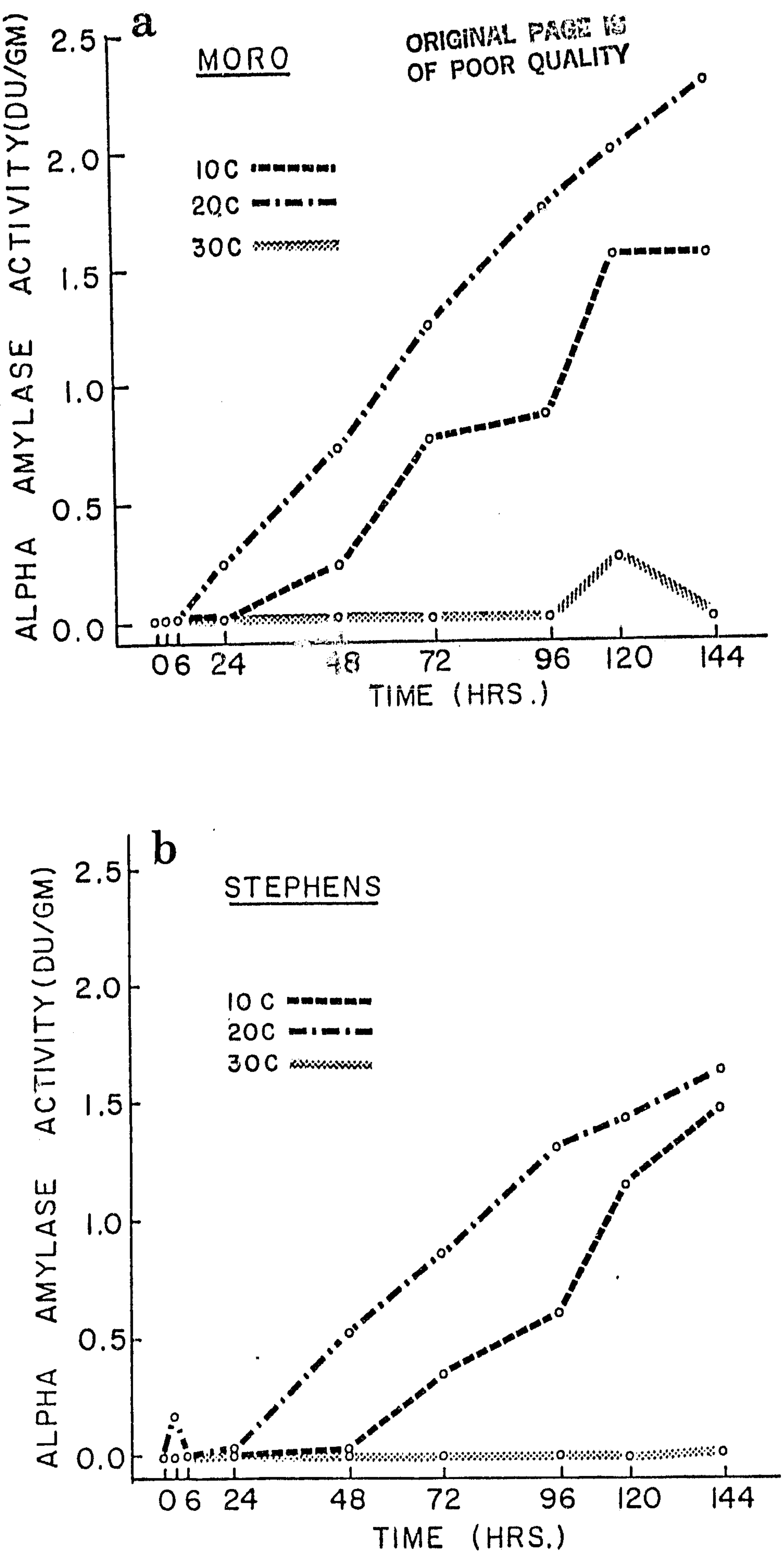

MORO
10 C
20 C
30 C
SCORE
0
2
4
6
0 3 6
24
48
72
96
120
144
TIME (HRS.)

Figure 12.


a
MORO
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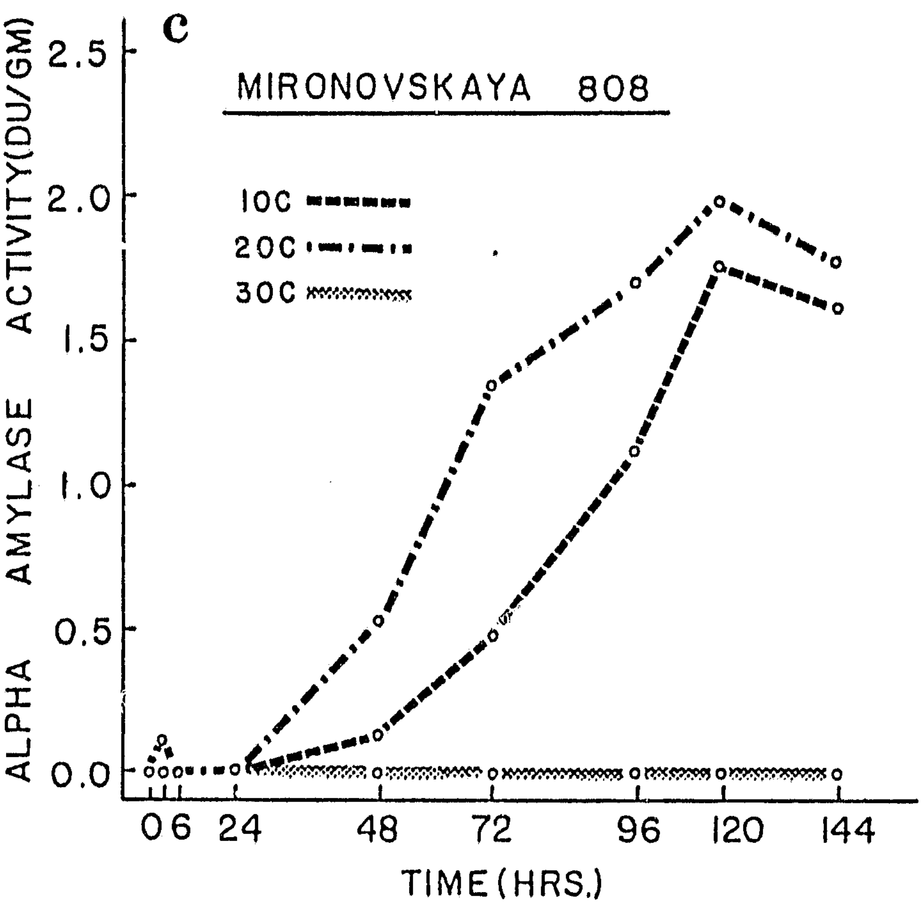
10C
20C
30C
ALPHA AMYLASE ACTIVITY (DU/GM)
2.5
2.0
1.5
1.0
0.5
0.0
0 6 24 48 72 96 120 144
TIME (HRS.)
b
STEPHENS
10 C
20C
30C
ALPHA AMYLASE ACTIVITY (DU/GM)
2.5
2.0
1.5
1.0
0.5
0.0
0 6 24 48 72 96 120 144
TIME (HRS.)

Figure 12.A


c
MIRONOVSKAYA 808
10C
20C
30C
ALPHA AMYLASE ACTIVITY(DU/GM)
2.5
2.0
1.5
1.0
0.5
0.0
0 6 24 48 72 96 120 144
TIME(HRS.)

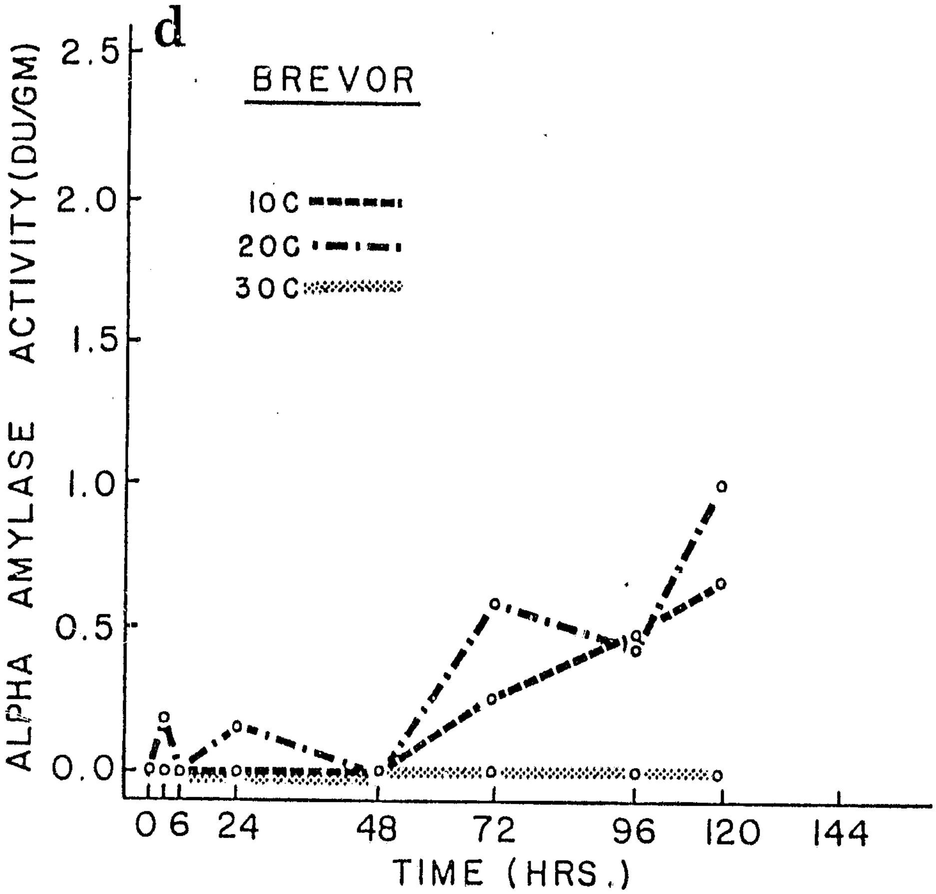

d
BREVOR
10C
20C
30C
ALPHA AMYLASE ACTIVITY(DU/GM)
2.5
2.0
1.5
1.0
0.5
0.0
0 6 24 48 72 96 120 144
TIME (HRS.)

Table 1.

Scoring system for seeds from intact heads

Score	Degree of Sprouting of the Seed
1	- No visible sign of sprouting
2	- Radicle emerged, 1-2 mm
3	- Coleoptile emerged
4	- Coleoptile 1 mm long
5	- Coleoptile 2-3 mm long
6	- Coleoptile 4-9 mm long
7	- Coleoptile 10-19 mm long
8	- Coleoptile 20-29 mm long
9	- Coleoptile 30-39 mm long
10	- Entering first leaf stage, coleoptile >40 mm long.

Scoring system for seeds in petri dishes

0	- Seeds hard
1	- Seeds soft, but no visible signs of sprouting
2	- 25% of the seeds show the first signs of sprouting
3	- Radicle appearance (5mm) on 25% of the seed
4	- Radicle appearance (5mm) on 50% of the seed.
5	- Shoot appearance on 25% of the seeds
6	- Shoot appearance on 50% of the seeds

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Table 2.

Growing conditions for the winter wheat cultivars at ten environmental conditions.

Abbrev.[+]	Location	Year	Soil Type	Planting Date	Heading Date	Harvest Date	Annual Rainfall[†] (cm)	Mean Monthly Temp (C°) May	June	July	Aug.
CF80	Central Ferry, WA	1980	Chard sandy loam (Calcic Haploxerolls, course-loamy, mixed, mesic)	10/3	5/19-26	7/22	43.9	16	19	24	27
CF81	Central Ferry, WA	1981	Chard sandy loam (Calcic Haploxerolls, course-loamy, mixed, mesic)	9/30	5/8-12	7/22	38.8	16	25	24	27
DA81	Dayton, WA	1981	Athena silt loam (Ultic Haploxerolls, fine-silty, mixed, mesic)	10/17	6/1-8	8/10	50.9	13	15	21	23
FE81	Cottonwood, ID	1981	Nez Perce silt loam (Xeric Agrialbolls, fine, montmorillonitic, mesic)	10/2	6/22-29	8/24	49.4	10	13	18	22
GR81	Grangeville, ID	1981	Nez Perce silt loam (Xeric Agrialbolls, fine, montmorillonitic, mesic)	10/2	6/22-29	8/24	59.2	10	13	18	20
OR80	Pendleton, OR	1980	Athena silt loam (Pachic Haploxerolls, fine-silty, mixed, mesic)	10/31	6/4-8	7/11	45.9	13	15	21	19
OR81	Pendleton, OR	1981	Athena silt loam (Pachic Haploxerolls, fine-silty, mixed, mesic)	10/24	5/28-6/6	7/21	53.4	13	16	20	22
SP80	Spillman Farm Pullman, WA	1980	Palouse silt loam (Pachic Ultic Haploxerolls, fine-silty, mixed, mesic)	10/27	6/12-19	8/12	53.6	11	13	18	16
SP81	Spillman Farm Pullman, WA	1981	Palouse silt loam (Pachic Ultic Haploxerolls) fine-silty, mixed, mesic)	11/4	6/5-12	8/11	56.8	11	13	17	20
WW81	Walla Walla, WA	1981	Walla Walla silt loam (Typic Haploxerolls, course-silty, mixed, mesic)	10/20	5/29-6/7	8/10	64.9	15	18	23	27

[+] Each environment will be referred to by this abbreviation throughout the paper.

[†] Annual rainfall during the growing season, September through August.

Table 3.

Percent germination at harvest ripe and after 8 weeks of storage of five winter wheat cultivars* grown at four different environmental conditions.

Location +		Germination Temperature									
		15C					30C				
		Harvest Ripe	Storage - 8 Weeks Temperature				Harvest Ripe	Storage - 8 Weeks Temperature			
			-10	10	20	30		-10	10	20	30
Central Ferry	1981	41	48	57	61	53	34	17	30	42	62
Ferdinand	1981	71	80	87	89	97	4	8	14	29	56
Oregon	1981	34	41	35	30	31	14	15	18	21	37
Spillman	1981	46	57	59	63	78	10	14	14	21	66
Mean		48	57	60	61	65	16	14	19	28	55

* Winter wheat cultivars were Moro, Nugaines, Wanser, Mironovskaya 808, and Bezostaya.

+ Locations - Central Ferry, WA; Ferdinand, ID; Pendleton, OR; and Pullman, WA.

Table 4.

Promptness Index at harvest ripe and after 8 weeks of storage of five winter wheat cultivars* grown at four different environmental conditions.

Location +		Germination Temperature									
		15C					30C				
		Harvest Ripe	Storage - 8 Weeks Temperature				Harvest Ripe	Storage - 8 Weeks Temperature			
			-10	10	20	30		-10	10	20	30
Central Ferry	1981	38	41	47	53	42	28	14	35	52	89
Ferdinand	1981	71	74	88	94	107	5	12	21	50	102
Oregon	1981	31	44	25	20	23	16	13	21	25	54
Spillman	1981	43	38	42	45	64	12	15	17	21	102
Mean		46	49	50	53	59	15	14	24	37	87

* Winter wheat cultivars were Moro, Nugaines, Wanser, Mironovskaya 808, and Bezostaya.

+ Locations - Central Ferry, WA; Ferdinand, ID; Pendleton, OR; and Pullman, WA.

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Table 5.

Percent germination at harvest ripeness and after 8 weeks of storage at 20C for 5 winter wheat cultivars grown at 4 environments.

		Germination Temperature(C)			
		15		30	
Cultivar	Location[+]	Harvest	8 Weeks	Harvest	8 Weeks
		----------------	%	----------------	
Mironovskaya 808	CF-81	47[†]	43	7	37
	FE-81	58	93	0	37
	OR-81	18	27	1	37
	SP-81	28	48	1	11
Bezostaya	CF-81	10	17	42	8
	FE-81	52	50	0	10
	OR-81	50	5	0	22
	SP-81	17	26	.2	11
Moro	CF-81	89	80	55	92
	FE-81	79	105	25	97
	OR-81	77	34	75	43
	SP-81	117	55	56	70
Nugaines	CF-81	25	34	32	44
	FE-81	98	17	0	5
	OR-81	5	21	4	11
	SP-81	19	50	2	10
Wanser	CF-81	23	98	7	67
	FE-81	81	108	0	77
	OR-81	7	19	1	2
	SP-81	44	59	2	5

[+] Locations were CF-81=Central Ferry, WA, 1981; FE-81=Ferdinand, ID 1981; OR-81=Pendleton, OR 1981; and SP-81=Pullman, WA 1981.

[†] The L.S.D. (0.10) to compare cultivar means within a time period is 25 and 28 for 15C and 30C, respectively, and to compare cultivar between locations is 33 and 26 for 15 and 30C, respectively.

Table 6. Effects of artificial rain and fertility type and level on amylograph measurements for the winter wheat cultivar 'Moro'.

	No Rain	Stage of Development at time of rain			
		Milky	Soft dough	Hard dough	Continuous
Amylograph Values	357	250	230	251	160

Fertilizer Type	Farm Yard Manure		NH_4NO_3		
Quantity/Acre	8 Ton	16 Ton	80 lbs.	160 lbs.	0
Amylograph Values	227	236	249	259	270

Table 8. Percent visual sprouting[+] at harvest for three winter wheat cultivars after artifical wetting of the heads at three stages of seed development.

Cultivar	Control	Stage of seed development			
		Milky	Soft Dough	Hard Dough	Continuous
	%				
Moro	0.1	0.4	1.0	0.3	1.3
Mironovskaya 808	0	0	0	0	0
Nugaines	0	0	0	0	0

[+] Sprouting was examined on 3 replications of 300 seeds each and sprouting was when the testa was ruptured or visual emergence of the radical had occurred.

Table 7. Effects of artificial wetting[+] of winter wheat heads on grain yield and yield components when averaged over three cultivars.

Stage of Seed Development	Grain Yield	Test Weight	200 Seed Wt.	Spikelets/ head	Heads/ m^2	Seeds/ spikelet	Seeds/ head	Lodging at harvest
	Mg/ha	Kg/hl	gm	no.	no.	no.	no.	%
No Water	4.15a	78.3a	7.22a	17.6a	598a	1.1a	20.5a	33a
Milky	4.33a	76.8cd	7.32a	17.8a	595a	1.3a	23.4a	33a
Soft Dough	4.32a	78.0ab	7.38a	17.8a	606a	1.2a	21.1a	34a
Hard Dough	4.36a	77.5abc	7.16a	17.9a	612a	1.3a	22.9a	34a
Continuous	4.50a	76.5c	7.31a	17.9a	562a	1.3a	23.9a	40a

[+] Wetting period was for 30 minutes at 8pm for 7-10 days during each of the seed development stages.

Table 9. Percent germination of three winter wheat cultivars+ after artificial wetting of the heads at three stages of seed development.

Time of Wetting	Germination Temperature (C) 15 Miron.	Moro	Nugaines	30 Miron.	Moro	Nugaines
	%					
Control	93	100	98	8	80	45
Milky	91	100	98	5	79	38
Soft Dough	89	100	97	7	70	47
Hard Dough	96	100	98	2	73	47
Continuous	95	100	99	7	81	40
Mean	93 b†	100 a	98 a	6 c	77 a	43 b

+ Winter wheat cultivars were Miron.=Mironovskaya 808, Nugaines, and Moro.

† Means within a row for an individual germination temperature followed by the same letter do not differ significantly at the 5% level of probability according to Duncan's Multiple Range Test.

Table 10. Germination index of three winter wheat cultivars+ after artificial wetting of the heads at three stages of seed development.

Time of Wetting	Germination Temperature (C) 15 Miron.	Moro	Nugaines	30 Miron.	Moro	Nugaines
	%					
Control	105	188	102	7	109	45
Milky	109	187	93	6	104	40
Soft Dough	94	183	98	6	103	49
Hard Dough	114	192	104	2	119	50
Continuous	108	192	117	7	125	45
Mean	106 b†	188 a	103 b	5 c	112 a	46 b

+ Winter wheat cultivars were Miron.=Mironovskaya 808, Nugaines, and Moro.

† Means within a row for an individual germination temperature followed by the same letter do not differ significantly at the 5% level of probability according to Duncan's Multiple Range Test.