A STUDY OF THE FACTORS
AFFECTING GRAIN SORGHUMS IN STORAGE

by

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INTRODUCTION

Grain production for food is an important agricultural industry and it is equally important to preserve the grain in storage in good condition for use at some future time. Grain storage, therefore, has developed into a large, modern, scientific and complex industry. A view of the grain industry as a whole will form a background from which to study the many problems relating thereto.

In the United States the average annual production of corn is approximately two and one-half billion bushels, all wheat eight hundred and fifty million bushels, oats one and one-quarter billion bushels, barley two hundred and fifty million bushels, and grain sorghums, in normal years, somewhat below one hundred million bushels. In all approximately six billion bushels of grain are produced and nearly all of it enters some kind of farm or commercial storage.

Grain storage begins on the farm. The grain may be stored on the ground with little damage in regions of limited rainfall. It may be stored in various types of temporary or permanent farm buildings. After the grain leaves the farm it may pass through the small country elevator, the interior terminal elevator, and the large modern reinforced concrete terminal elevator at the central market. The amount of these grains entering into commercial channels is cared for by these different types of commercial storage. The combined storage capacity of sixteen of the leading grain storage centers in the United States is approximately four hundred fifty million bushels. When the secondary storage capacity is added, it readily can be seen that improper methods of caring for this large volume of grain from harvest time to the time of consumption might entail large losses due to damage.

There are many hazards to be considered by the owner of stored grain. The grain may go out of condition or the price may decline. Price decline may be insured by hedging practices and insurance may be carried against grain dust and fire hazards. These are economic in aspect and will not further be considered. We are interested principally in the factors involved in keeping the grain in good merchantable condition.

These investigations were outlined to study the factors related to the storage of kafir and milo. The principal factors involved in the safe storage of these grains appear to be moisture content of the grain, temperature of the grain when stored and during period of storage, rate of respiration, presence or absence of insects, influence of molds, and the percentage of broken grains present. The opinion has been held by some that grain sorghums are more sensitive to factors affecting the grain in storage than are some of the other cereals. These studies were undertaken with the hope of adding to our present knowledge of conditions affecting the storage of these grains.

REVIEW OF LITERATURE

Much has been said and written about the keeping qualities of the grain sorghums but a search of the literature reveals little definite, scientific research. It has been the general opinion that grain sorghums are more difficult to keep in storage than other cereal grains, yet most investigations of a basic nature have been conducted with wheat, corn, oats or barley.

In this review of literature it is assumed that the major factors which may cause wheat or corn in storage to deteriorate, similarly affect the grain sorghums in storage. It is on this assumption that free use is made of the literature relating to any cereal grains.

Moisture

The moisture content of grain is one of first importance. Bailey and Gurjar (10) assumed that moisture in grain existed as imbibed water in loose combination with the organic colloids. These colloids form the principal constituents of the wheat kernel and imbibe large quantities of water which form elastic gels. It may be seen that moisture is intimately associated with the cells of which the kernel is composed. The colloid particles which form much of these cells are extremely minute and thus expose relatively large surfaces for the absorption of water. Most colloids of grain appear to be hydrophilic and adsorb water freely. Coleman, Rothgeb, and Fellows (18) say that cereal grains are hygroscopic and tend to lose or gain moisture to reach an equilibrium with atmospheric conditions. Alberts' (2) investigations show that with corn the moisture content varies directly with the relative humidity of the atmosphere. Bidwell, Bopst, and Bowling (15) found a difference in the capacity of kafir, milo, and feterita to take up water due to the hardness compactness of the grain. Their findings show that the interior portions of kafir and milo are harder and more glassy than that of feterita.

There are several factors which have a direct influence on the amount of moisture contained in grain in a safe storage condition. The official grain standards of the United States permit 14 per cent moisture in grain sorghums grading Number 1. Bailey (7) reports that wheat containing 14.5 per cent moisture when stored under normal conditions in a temperate climate would not heat, but wheat containing 15.5 per cent moisture was almost certain to heat. The Board of Grain Commissioners of Canada (16) report that the highest moisture observed in any car of wheat arriving at Port Arthur in good condition contained 16.5 per cent. They conclude that wheat containing slightly less than 14.7 per cent moisture is the limit of safety for sound wheat. Swanson and Fenton (59) state that any wheat stored with a moisture content of 15 per cent or higher is likely to be damaged by heating. Humphries and Hurst (29) found that a moisture content of 14 per cent for cereal grains, 16 per cent for soybeans, and 11 per cent for flax seed is usually low enough for safe storage.

The effect of harvest conditions has been studied by many investigators. Since "combine" harvesting has become popular in recent years, the moisture content of the grain at harvest time has become more important. McCalla, Cameron, and Sinclair (43) found in Canada there was a gradual reduction in the moisture content of standing wheat from 25.9 per cent on August 25, to 11 per cent on September 7. In cool seasons the moisture content did not decline as rapidly, and not as low. McCalla, Larmour, Geddes, and Malloch (44) state that four to seven days must elapse from the time the grain is ready to cut with a binder before it is ready to cut with a combine to obtain straight grade grain. They also report an increase in moisture content from 12.7 per cent to 26 per cent in four hours due to rain, and the subsequent drying is much slower than the wetting. Von Trebra (66) working with grain sorghums at Manhattan, Kansas, in 1931, found that Western Blackhull kafir, when it was considered ripe before frost, contained as high as 32 per cent moisture on September 18. The moisture gradually declined and reached a minimum about ten days after the first frost. After standing longer in the field the moisture content increased appreciably. In 1932 the moisture content was much lower throughout the season, due to less precipitation during the period concerned. Aicher (1) says that at Hays, Kansas, sorghum grains having a moisture content slightly over 13.5 per cent will keep in bins throughout the winter months, but there is danger of heating with the coming of summer temperatures. Laude and Swanson (36) report that sorghum grain with 15.9 per cent moisture heated under May temperature conditions, and that grain containing 12 per cent moisture can generally be stored with safety. Martin et al (40) say grain sorghums may contain 11 to 20 per cent moisture at harvest and place 13 per cent as the limit for safe storage. Bainer (11) reports successful drying of rice with an artificial drier, while Conrad and Stirniman (20) mention the location of many commercial driers in California that dry grain sorghums successfully.

Temperature

It is possible for grain with high moisture content to remain in good condition in storage if the temperature remains sufficiently low. During periods of relatively high temperature grain may keep in storage if the moisture content is low. Bailey and Gurjar (10) made observations on wheat containing 14.96 per cent moisture at 4 degrees C. and up to 75 degrees C. They found small variation between 4 degrees C. and 25 degrees C. but at higher temperatures respiratory activity increased greatly, with a maximum at 55 degrees C. Beyond this temperature there was a rapid decline in the activity of the life processes of the kernel. Coleman, Rothgeb, and Fellows (18) found the rate of respiration was approximately two times as high in grain sorghums at 37.8 degrees C. as at 27.8 degrees C. The difference or ratio in respiratory rates recorded was little influenced by the moisture content. The increases in respiration due to higher moisture content were in all cases approximately proportional. Schmorl (53) states that safe storage calls for low moisture and low temperature. The enzymes react more slowly at lower temperatures and if the temperature is too low this may interfere with the after-ripening process which is beneficial to the storage of new crop grain. Sherwood et al (54) conclude that the rate of increase in acidity depends primarily upon the temperature of storage. Swanson's (58) investigations revealed that wheat samples stored at 60 degrees F. were sound up to 20 per cent moisture but at 95 degrees F. nearly all samples above 11.1 per cent moisture suffered damage. He concludes that this shows the importance of low temperatures in preventing damage to high moisture wheat.

Respiration

According to Miller (46) respiration is a process of the living cell whereby energy is released. Swanson (61) says a kernel of grain is a living organism, and that respiration is a phenomena of living organisms and is a release of energy. Bailey (9), (10) defines respiration as the release of energy through the biochemical oxidation of organic compounds as accelerated by certain enzymes. Coleman, Rothgeb, and Fellows (18) say that energy for many life processes and reactions is released in the living cell in an exothermic or heat-developing reaction or a succession of reactions known collectively as respiration. Miller (46) says one of the striking results of respiration is the loss in weight of the organism and that it proceeds at an ordinary temperature. According to McGinnis (45) the formation of 100 grams of carbon dioxide required 61.36 grams of carbohydrate material and the amount of carbohydrate lost may be calculated as 61.36 per cent of the carbon dioxide evolved. For wheat this gave 10.038 grams of carbohydrate per 100 grams of dry matter in 16 days.

There are two kinds of respiration. Normal or aerobic respiration, also called oxygen respiration, occurs in the presence of free or a normal supply of oxygen. Anaerobic respiration, sometimes called fermentation and intra-molecular respiration, occurs in the absence of a free supply of oxygen. Schmorl (53) says the end products of (aerobic) respiration or combustion are carbon dioxide, water vapor, and heat as shown by the formula:

$$C_6H_{10}O_5 + 6\,O_2 \longrightarrow 6\,CO_2 + 5\,H_2O + \text{Heat}$$

$$\text{Starch of kernel} + \text{Oxygen} \longrightarrow \text{Carbon dioxide} + \text{Water vapor} + \text{Heat}$$

Miller (46) gives the formula for anaerobic respiration as

$$\underset{\text{Glucose}}{C_6H_{12}O_6} \longrightarrow \underset{\text{Ethyl Alcohol}}{2\,C_2H_5OH} + \underset{\text{Carbon dioxide}}{2\,CO_2}$$

Decomposition of organic compounds may be accomplished by rearrangement of atoms within the molecule without the supply of additional oxygen. This is sometimes called alcoholic fermentation.

Molds

Swanson (60) states that the processes causing damage in wheat with high moisture content are usually accompanied by mold growth and heating. Gilman and Barron (25) say the molds commonly found on stored grain are *Aspergillus niger*, *A. flavus*, and *A. fumigatus*. Bakke and Noecker (12) isolated from grain in Dewar flasks *A. niger*, *A. flavus*, *Rhizopus* sp., *Fusarium* sp., *Penicillium* sp., and several species of bacteria. Hurd (30) says *Penicillium* and *Rhizopus* are the two omnipresent molds which cause much trouble in blotter germinations in the laboratory. She also mentions that *Rhizopus* was not found attacking seeds in storage or in the soil, and that neither of these fungi was ever found on healthy, unbroken seeds. Robak (51) reports common molds which attack corn are *Penicillia*. Finnell (23) says that chalk white seeded varieties of grain sorghums do not resist decay as well as ivory white, nor the ivory white as well as yellow.

Insects

Grain infested with insects, according to Lindgren (38), probably will go out of condition sooner than uninfested grain. The metabolic water and heat given off by the insects no doubt hasten this process and may even initiate it. Weevil become less active in grain containing less than 14 per cent moisture and apparently cannot long live in grain containing 10 per cent or less moisture. Back and Cotton (5) report that Baston recorded observations on 15,000,000 bushels of wheat stored at Buffalo during war-time by the United States Grain Corporation. This wheat carried a moisture of 11.3 to 12.6 per cent and some developed heating during the winter. Of 977 bins which were transferred, 374 were in good condition, 396 contained weevil and beetle infestation, and 207 were heavily infested with insects.

Table showing general condition of wheat, average moisture, average temperature, for good, slightly infested, and highly infested wheat.

Condition	Average Moisture	Damaged Per Cent	Time of Storage	Average Temperature
Good, no insects	12.6	3.1	105 days	66.2 F.
Trace of insects	11.3	2.9	118	69.3
Highly infested	12.2	2.9	90	78.3

Back and Cotton (4) and Back (6) name two weevil as being most prevalent in grain in the United States, the granary weevil, Sitophilus granarius L., and the black or rice weevil, Sitophilus oryza L. The angoumois moth, Sitotroga *cerealella* Oliv., is also a common grain pest.

Broken Grains

It has been generally believed that a large proportion of broken grains is an important factor in grain storage. Most writers are in agreement that injured or broken tissue, or grain, respires at a greater rate than healthy tissue, or uninjured grain. In order to supply definite data on this subject Coleman, Rothgeb, and Fellows (18) made a study of the respiratory activity of whole and broken grains of Freed sorgo. Their observations indicate little difference at low moisture contents and only when the moisture reached 16 per cent did the cracked grains show a marked increase in rate of respiration. Tashiro (63) says all living seeds are metabolically active and respond to injury by giving off more CO_2 on crushing. Martin, Reynoldson, Rothgeb, and Hurst (41) found that at harvest time kafir contained an average of 7.5 per cent of broken grains and milo, an average of 21 per cent. Grain harvested with a combine was found to contain more foreign material and cracked grain than that harvested in a different manner. Kafir contained an average of 4.3 per cent material classified as "foreign material and cracked grains" and 5.7 per cent coarsely broken grain. Milo contained an average of 8.7 per cent and 17.3 per cent respectively.

Germination

The factors which influence storage conditions of grain also affect viability of the grain. Simpson (55) found that cotton seed containing 8 per cent moisture or less, retained viability for four and one-half years. Cotton seed with 13.78 per cent moisture and stored to prevent loss of moisture lost all viability in nine months. Karper and Jones (34) observed that Blackhull kafir which showed 100 per cent germination in 1917, showed viability as follows:

1924	88 Per cent
1926	79.5
1927	65.0
1929	48.0
1931	34.2
1933	15.5
1935	4.0
1936	0.5

These authors report Ayyangar and Ayyar of the Agricultural Research Institute of Coimbatore, India, found that sorghum seed preserved in the head showed about 90 per cent viability for three or four years but did not germinate when seven years old. Threshed seed stored in bottles showed only 10 per cent germination at the end of four years. Robertson and Lute (52) observed in the climate of Colorado wheat lost only 7 per cent germination in 10 years and barley lost 14 per cent in the same time. Rosen rye and Wisconsin Black soybeans lost about 10 per cent germination in five years.

Black Amber sorghum seed lost only two per cent in six years. They make the general statement that seed of small grain crops stored in a dry, unheated room at Fort Collins, retain a high percentage of viable seeds when ten years old. Sonavne (56) shows that the viability of sorghum, wheat, maize, cotton, and flax in India at six and seven years is considerably reduced, and at ten years sorghum, flax and wheat show germination of 7.2, 3.5, and 0.3 per cent respectively. Harrington (26) found no qualitative relation between water content and germinability. He also says that after-ripening progresses at the same time as normal loss of water during the curing of grain, but not primarily as a result of it. Lafferty (35) states that Ohga reports finding viable seeds of the Indian Lotus deeply imbedded in peat deposits in Manchuria which he believes to be 200 years old. Swanson's (58) data on wheat showed a reduction in germination to zero percentage at 20 per cent moisture at laboratory temperatures but a continued high germination (above 90) at 20 per cent moisture when maintained at low temperatures. Low temperature seemed to be the important factor in preventing injury to viability. Excluding air had a small detrimental effect, even at low temperature.

METHOD OF STUDY

Samples of kafir and milo were placed in glass containers and stored in basement rooms. One room was heated to normal laboratory temperature and the other room remained cool at all times. The first experiment was done during March and April when outdoor temperatures were cool. The experiment was repeated, with some minor changes, in the same rooms in June and July when the warm outdoor temperature raised the temperature of the "cool" room thereby reducing the difference in temperature.

Description of Experiment

The experiment was divided into Part 1 and Part 2. Part 1 concerns the study of storage conditions of kafir and milo containing moisture from 10 to 22 per cent stored in varying temperature conditions, for different lengths of time, and with treated seed, as shown in Table I. By referring to Plates I, II, III, and IV in connection with a study of Table I, the plan of Part 1 of the experiment may more easily be understood.

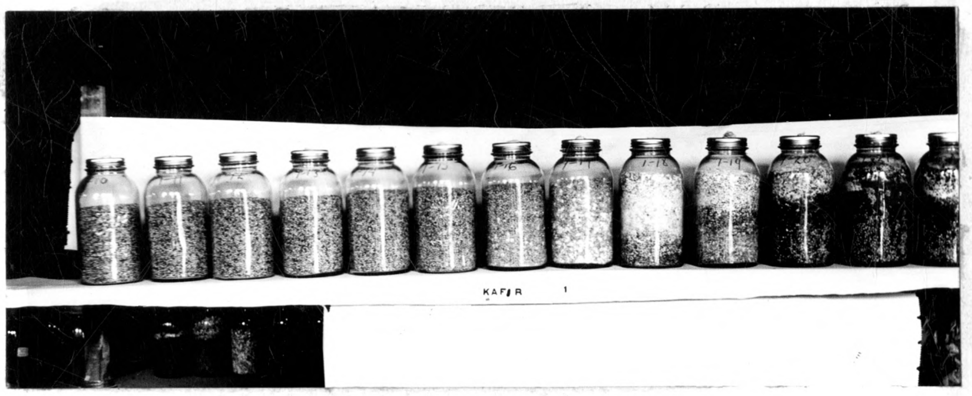
Plate I.

Kafir. Series 1. Second experiment, warm temperature. Increasing moisture content from left to right.

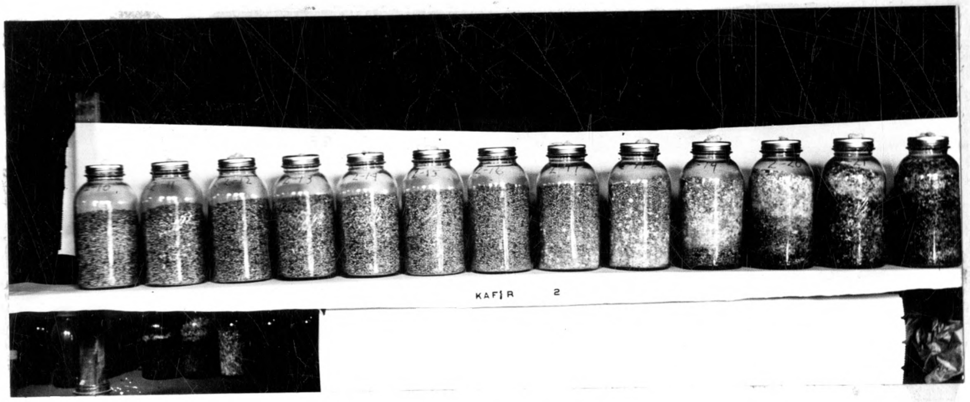
Kafir. Series 2. Second experiment, cool temperature. Increasing moisture content from left to right.

Kafir. Series 3. Second experiment, warm temperature and treated with Semesan. Increasing moisture content from left to right.

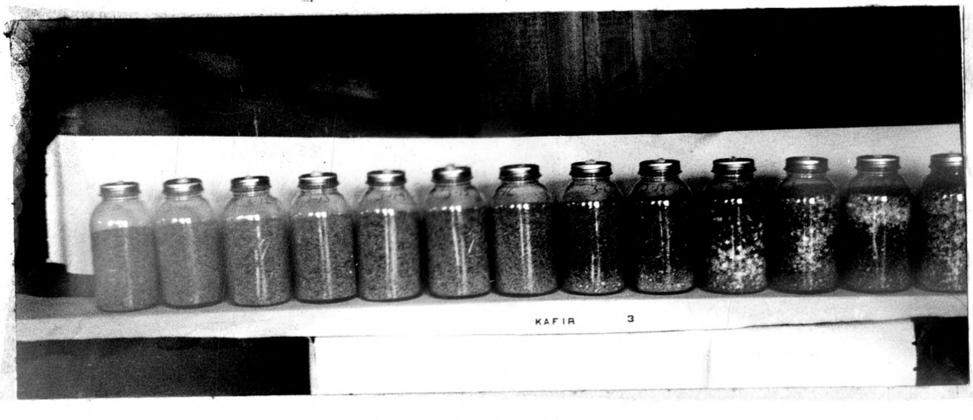
Plate I.



Series 1. Kafir.



Series 2. Kafir.



Series 3. Kafir.

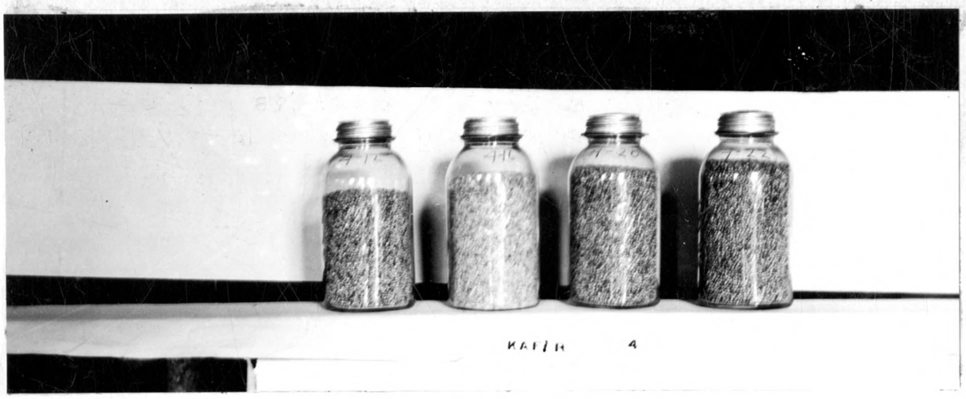
Plate II.

Kafir. Series 4. Second experiment, warm temperature and sealed. Increasing moisture content from left to right.

Kafir. Series 5A. Second experiment, warm temperature and removed from the experiment at the end of four weeks. Increasing moisture content from left to right.

Kafir. Series 5B. Second experiment, warm temperature and removed from the experiment at the end of two weeks. Increasing moisture content from left to right.

Plate II.



Series 4. Kafir.

Series 5A. Kafir.

Series 5B. Kafir.

Plate III.

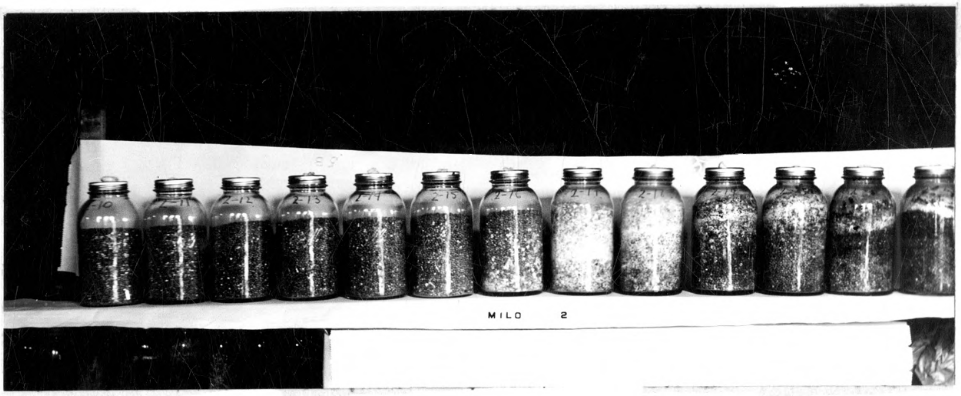
Milo. Series 1. Second experiment, warm temperature. Increasing moisture content from left to right.

Milo. Series 2. Second experiment, cool temperature. Increasing moisture content from left to right.

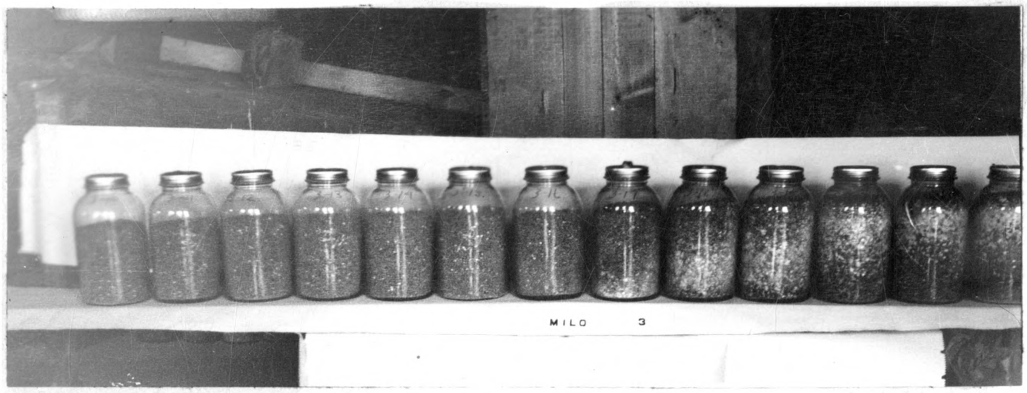
Milo. Series 3. Second experiment, warm temperature and treated with Semesan. Increasing moisture content from left to right.

Plate III.

Series 1. Milo.



Series 2. Milo.



Series 3. Milo.

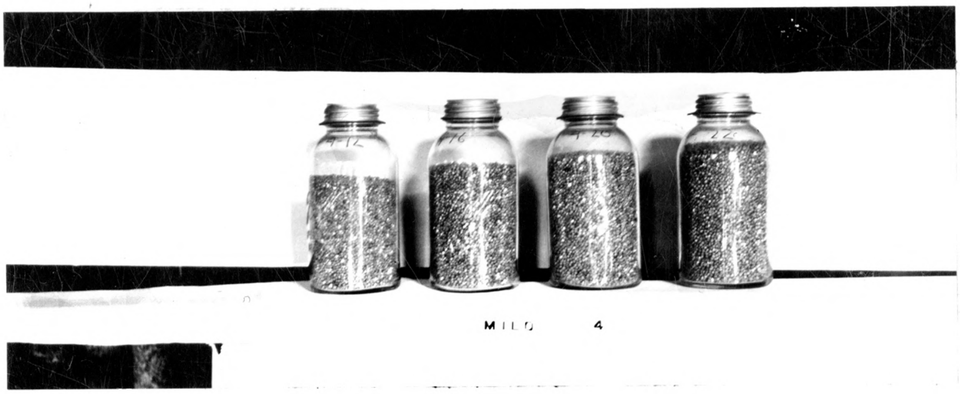
Plate IV.

Milo. Series 4. Second experiment, warm temperature and sealed. Increasing moisture content from left to right.

Milo. Series 5A. Second experiment, warm temperature and removed from the experiment at the end of four weeks. Increasing moisture content from left to right.

Milo. Series 5B. Second experiment, warm temperature and removed from the experiment at the end of two weeks. Increasing moisture content from left to right.

Plate IV.



Series 4. Milo.

Series 5A. Milo.

Series 5B. Milo.

Table I. Plan of experiment. Part 1.

Moisture Content Per Cent	Series 1 Warm	Series 2 Cool	Series 3 Warm Treated	Series 4 Warm Sealed	Series 5 A Warm Removed 4 Weeks	Series 5 B Warm Removed 2 Weeks
10	X	X	X		X	X
11	X	X	X			
12	X	X	X	X	X	X
13	X	X	X			
14	X	X	X		X	X
15	X	X	X			
16	X	X	X	X	X	X
17	X	X	X			
18	X	X	X		X	X
19	X	X	X			
20	X	X	X	X	X	X
21	X	X	X			
22	X	X	X	X	X	X

Series 1, 2, and 3 each contained thirteen containers with 1000 grams of kafir, with moisture content increasing by single percentages from 10 to 22. Series 1 was stored at the warm temperature, Series 2 at the cool temperature and in Series 3 the grain was treated and stored at the warm temperature.

Series 4 contained only four samples with moisture contents of 12, 16, 20, and 22 per cents. These containers were sealed to be used as moisture loss checks and were stored at the warm temperature.

Series 5A and 5B each included samples of kafir with 10, 12, 14, 16, 18, 20, and 22 per cents of moisture, and were stored at the warm temperature. Series 5B was removed from the experiment at the end of two weeks for moisture determinations and to study the time factor in relation to other factors. Series 5A was likewise removed at the end of four weeks.

All series as described for kafir were duplicated under the same conditions using milo. All of Part 1 of the experiment was repeated in the early summer under slightly different temperature conditions. The warm temperature conditions were somewhat similar to those during the first experiment but the cool temperature did not remain as low as in the previous experiment. This more nearly approached natural storage conditions that usually obtain in normal seasonal conditions.

Part 2, as shown in Table II, was designed to study the effect of different percentages of broken kernels in stored grain. The percentages of broken grain in the first experiment used were 4, 8, 12, 15, 20, and 25. These percentages are the same as permitted in the federal grades for grain sorghums up to and including 15 per cent. The higher percentages were added to widen the range of study to excessive broken grain content. In the second experiment the two lower percentages were eliminated as it was believed that their importance did not justify their continuance.

Samples with each percentage of broken grain were made up to moisture contents of 10, 12, 14, 16, 18, 20, and 22 per cent. This part of the experiment was duplicated, one group of samples being stored at the warm temperature and one group at the cool temperature. This afforded the opportunity to observe and obtain data on the effect of both the range of moisture and range of broken grains under each temperature condition. This part of the experiment was repeated during the early summer when Dwarf Yellow milo was used instead of kafir.

Table II. Plan of experiment. Part 2.

Moisture Content Per Cent	4% Broken Grain	8% Broken Grain	12% Broken Grain	15% Broken Grain	20% Broken Grain	25% Broken Grain
10	X	X	X	X	X	X
12	X	X	X	X	X	X
14	X	X	X	X	X	X
16	X	X	X	X	X	X
18	X	X	X	X	X	X
20	X	X	X	X	X	X
22	X	X	X	X	X	X

Kind of Containers

Glass jars of one-half gallon capacity were used. It was found that 1000 grams of grain filled these containers about two-thirds full, leaving ample space for increase in volume of grain when it swelled due to the addition of water. Special metal lids consisting of two parts were used. A hole about the size of an ordinary lead pencil was punched through the center of each lid, with the exception of the sealed series. The holes were plugged with cotton to limit the entrance of spores but allow free passage of air through the cotton. Aerobic conditions were thus obtained in all containers except the sealed series which approached anaerobic conditions.

The Grain Used

The kafir used for the first experiment was Blackhull kafir obtained from the Agronomy farm where it had been stored for some time. It was slightly immature and had a weight per bushel of 56.2 pounds, a moisture content of 16.51 per cent, and a germination of 80 per cent. The grain was exceptionally clean and bright except for the green kernels due to immaturity, and contained no broken grain. This kafir was used for both Part 1 and Part 2 in the first experiment.

The milo used in the first experiment was Wheatland which weighed 56.8 pounds per bushel, contained 12.88 per cent moisture, and had a germination of 65 per cent. It was stored for some time in the warmed basement of a building, which probably accounts for the lower moisture content. The milo was run over the 5/64 inch triangular sieve to remove the broken grain and contained eight per cent broken grain too large to pass through the sieve.

The kafir used in the second experiment was from the same source as that used for the first experiment. The moisture had been reduced to 8.49 per cent and the germination had declined to 61 per cent.

The milo used in the second experiment was Dwarf Yellow milo, bright, with a moisture content of 7.59 per cent, a germination of 74.5 per cent, and a weight of 57.6 pounds per bushel. Samples of 1000 grams each were used in all cases.

The Addition of Water

The samples of 1000 grams were weighed and the amount of water required to bring each sample up to the desired per cent of moisture was calculated and added. The grain was thoroughly mixed several times each day for the first three days to distribute the moisture as evenly as possible throughout the mass of grain.

Conditions of Storage

The series which are designated as stored at a warm temperature were stored in a basement room where the average temperature for the first experiment was 33.2 degrees C. (91.7 F.). The series which are designated as stored at a cool temperature were stored in a basement room where the average temperature was 19.7 degrees C. (67.4 F.).

The maximum fluctuation in temperature was about 4 degrees C. above to about 5 degrees C. below the average for the warm room, and 4 degrees C. above to 6 degrees C. below the average for the cool room. The usual variation in temperature was only about two degrees C. from the average. The difference between the average warm and the average cool temperature was 13.5 degrees C.

During the second experiment the average warm temperature was 33.4 degrees C. (92.1 F.), and the average cool temperature was 27.9 degrees C. (82.2 F.), or a difference of only 5.5 degrees C. The maximum fluctuations from the average temperatures were about the same as during the first experiment except a gradual rise in the average cool temperature. This temperature averaged nearly 10 degrees C. warmer during the last week of the experiment as compared with the average of the first week.

Methods of Making Moisture Tests

Much investigational work has been done to standardize methods of determining the amount of moisture in grain and other substances. After a study of the electrical resistance method (Tag-Heppenstall), the Brown-Duvel method, and various oven methods, it was decided to use the electric air oven, as approved by the Association of Official Agricultural Chemists (69) for the moisture tests of the grain in these experiments. An electric air oven was maintained at 135 degrees C. $\pm$ 2 degrees and a sample of approximately two grams was heated in the oven for two hours. This method was used in preference to the more rapid electrical resistance method as it was believed greater accuracy could be obtained in the grain containing high moisture and where the moldy condition of the grain made it difficult to obtain uniformity of results on the electric moisture tester.

Duration of the Experiment

Each experiment was conducted for a period of six weeks, with the exception of Series 5B which was removed at the end of two weeks, and Series 5A which was removed at the end of four weeks. All samples were weighed once each week, the total weight being recorded, and the loss in weight calculated.

EXPERIMENTAL RESULTS. PART 1

Moisture Studies

As shown previously under methods of study, the plan of the experiment was to include samples of kafir and milo with established moisture contents of 10 to 22 per cent, increasing the moisture content in the first three series by single percentages. The low moisture content of 10 per cent was low enough to represent dry grain and the upper limit was established well above the known limit of moisture for safe storage, to study the developments caused by excessive moisture.

The moisture content of kafir and milo has received more consideration since the advent of the combine method of harvesting. It has long been the opinion of many that grain sorghums are more difficult to keep in storage than other cereal grains. Many reasons for this opinion have been advanced, but the most logical ones seem to be the season of the year when the grain is harvested and the relatively high amount of foreign material such as broken pieces of stalk, broken grains, and other foreign material. Grain sorghums are harvested late in the season, sometimes after frost, when the relative humidity of the atmosphere usually is high and therefore the grain contains a comparatively high amount of moisture. Due to cool weather which prevails in the fall and through the winter, grain sorghums may keep safely until the warm weather of the following spring. Wheat is usually harvested when the summer temperature is high and the relative humidity low, which causes the grain to dry to a low moisture content before going into storage.

Since the kafir used in the first experiment contained 16.51 per cent moisture and the milo 12.88 per cent, the parts of the experiment to have less than these amounts were not included in the summaries. However the containers were filled and the data were used to measure the variability of sampling. These data are reported in the tables and may serve as an indication of fluctuation or variation in experimental data. The kafir and milo used in the second experiment had moisture contents well below the minimum established for the beginning.

Temperature greatly influenced the loss of moisture in damp grain. By referring to Table III and Figure 1 showing the amount of moisture in the kafir at the end of the experiment, a rather striking difference will be seen to exist between Series 2, maintained at a cool temperature, and Series 1 and 3 maintained at a warm temperature. At the cool temperature there was little change in the moisture content of the grain during the six weeks of the experiment. At 22 per cent original moisture there was an increase of less than one-half of one per cent in moisture content in the cool series, as compared with an increase of approximately 10 per cent in moisture when the grain was stored at a warm temperature. This difference in final moisture content was probably due in a large measure to the excessive mold development, and the respiration of the mold. This is in agreement with the moisture content of Series 4, where the grain was sealed and no observable mold developed due to the absence of free oxygen, or anaerobic conditions. The excessive moisture content appears to correspond closely with the development of molds. This is again shown by comparing the moisture at different times during the experiment. The sample containing 22 per cent moisture at the beginning of the experiment, contained only 21.16 per cent moisture at the end of two weeks. There was a slow development of mold during this time. During the period from two to four weeks the mold developed most rapidly, and there was almost a maximum growth at the end of this period. The moisture content had increased to nearly 26 per cent while at the end of six weeks the moisture had increased to above 31 per cent. In addition to the respiration of the grain, there appeared to be two causes for this high moisture content, namely, the continued excessive respiration of the molds, and their consumption of carbohydrates which lowered the weight of the grain.

It is interesting to note the very small change in the moisture content of the grain in Series 4. This series was sealed and anaerobic conditions maintained. There was no mold that could be observed and the samples lost or gained very little moisture. The sample containing 22 per cent original moisture had increased to only 22.60 per cent, probably due to anaerobic respiration and alcoholic fermentation which was decidedly evident when the container was opened at the end of the experiment.

In general similar results prevailed with milo, as shown by Table IV and Figure 2. The moisture content under warm conditions was not as high in the 22 per cent moisture samples except at the end of the first two weeks, which may indicate a quicker development of molds on milo than on kafir. It may be mentioned that all results concerned with the high moisture samples may lack uniformity. The heavy mold growth, and in many instances the extremely bad condition of the grain, made it difficult to obtain uniform samples for laboratory tests. Table V shows the moisture content of kafir at the end of the second experiment. Up to approximately 16 per cent original moisture content, Series 2, with cool temperature, lost consistently less moisture than either Series 1 or 3 which were maintained at warm temperatures. Above 16 per cent original moisture, or at about the point of heavy mold development the cool series showed less moisture. This in general, compares with the amount of mold present, which was greater under warmer conditions.

As in the first experiment the moisture content of the kafir containing 22 per cent at the beginning of the second experiment had increased slightly, or to 22.70 per cent at the end of two weeks. At the end of four weeks, during which time there was much mold growth, the moisture had increased to 27.86 per cent, or nearly as much as at the end of six weeks. This shows that the mold became firmly established in the high moisture grain during the first two weeks but that the heavy growth occurred during the second two-week period. The mold growth at the end of the second two-week period had almost reached the maximum as far as completely covering the top of the grain was concerned. The results with milo were similar to kafir in the lower range of moisture. The higher moisture content of the cool series continued higher than the warm series throughout the higher moisture range.

Table III. Kafir. Part 1. Summary of moisture content at end of first experiment.

Moisture Content Per Cent	Series 1 Warm	Series 2 Cool	Series 3 Warm Treated	Series 4 Warm Sealed	Series 5A Warm Removed 4 Weeks	Series 5B Warm Removed 2 Weeks
	14.32	15.34	14.08	-----	16.25	16.22
	13.84	14.79	14.20	-----	-----	-----
	16.13	15.49	14.00	16.84	15.73	15.66
	15.14	15.40	14.17	-----	-----	-----
	15.31	15.46	14.48	-----	15.44	16.36
	15.40	15.96	14.67	-----	-----	-----
16	16.28	14.98	13.86	16.01	15.84	17.84
17	15.89	16.60	15.05	-----	-----	-----
18	17.34	17.12	16.40	-----	19.62	18.50
19	21.11	17.60	18.53	-----	-----	-----
20	24.84	19.90	21.17	19.68	20.92	21.69
21	28.01	22.10	25.29	-----	-----	-----
22	31.18	22.48	33.27	22.60	25.94	21.16

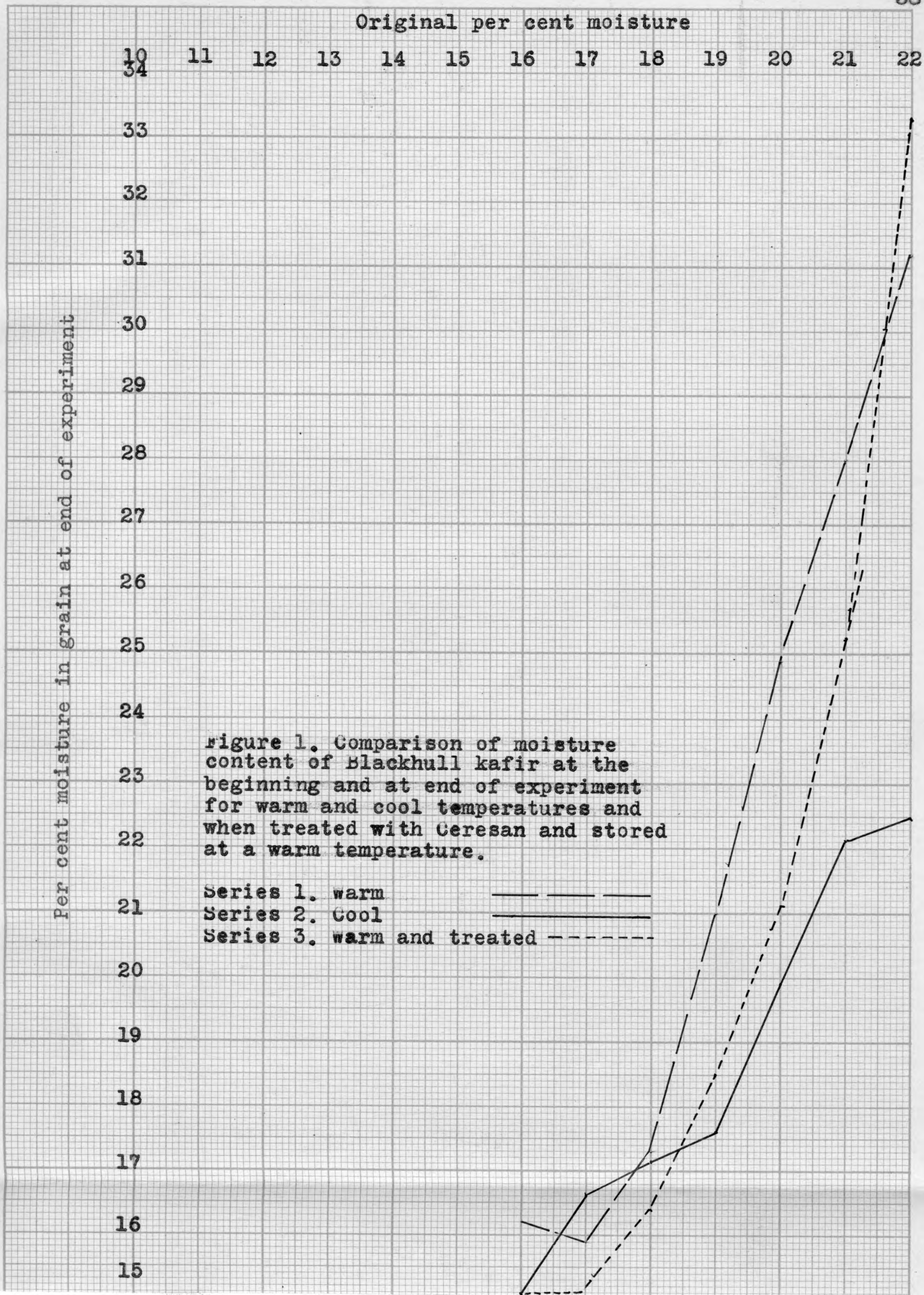


Figure 1. Comparison of moisture content of Blackhull kafir at the beginning and at end of experiment for warm and cool temperatures and when treated with Ceresan and stored at a warm temperature.

Table IV. Milo. Part 1. Summary of moisture content at end of first experiment.

Moisture Content Per Cent	Series 1 Warm	Series 2 Cool	Series 3 Warm Treated	Series 4 Warm Sealed	Series 5A Warm Removed 4 Weeks	Series 5B Warm Removed 2 Weeks
	10.75	11.32	10.90	-----	12.70	12.72
	12.32	11.09	10.97	-----	-----	-----
12	11.04	11.85	9.91	11.91	12.53	12.88
13	10.98	12.39	9.51	-----	-----	-----
14	11.98	12.25	11.74	-----	13.93	13.85
15	13.60	13.81	11.84	-----	-----	-----
16	15.28	14.23	13.09	17.09	16.15	15.95
17	15.65	15.74	16.22	-----	-----	-----
18	17.95	15.77	17.53	-----	18.95	19.06
19	24.45	18.87	21.73	-----	-----	-----
20	27.64	20.34	24.23	20.74	23.31	21.95
21	25.85	21.17	29.93	-----	-----	-----
22	28.29	22.61	29.59	22.33	24.61	25.21

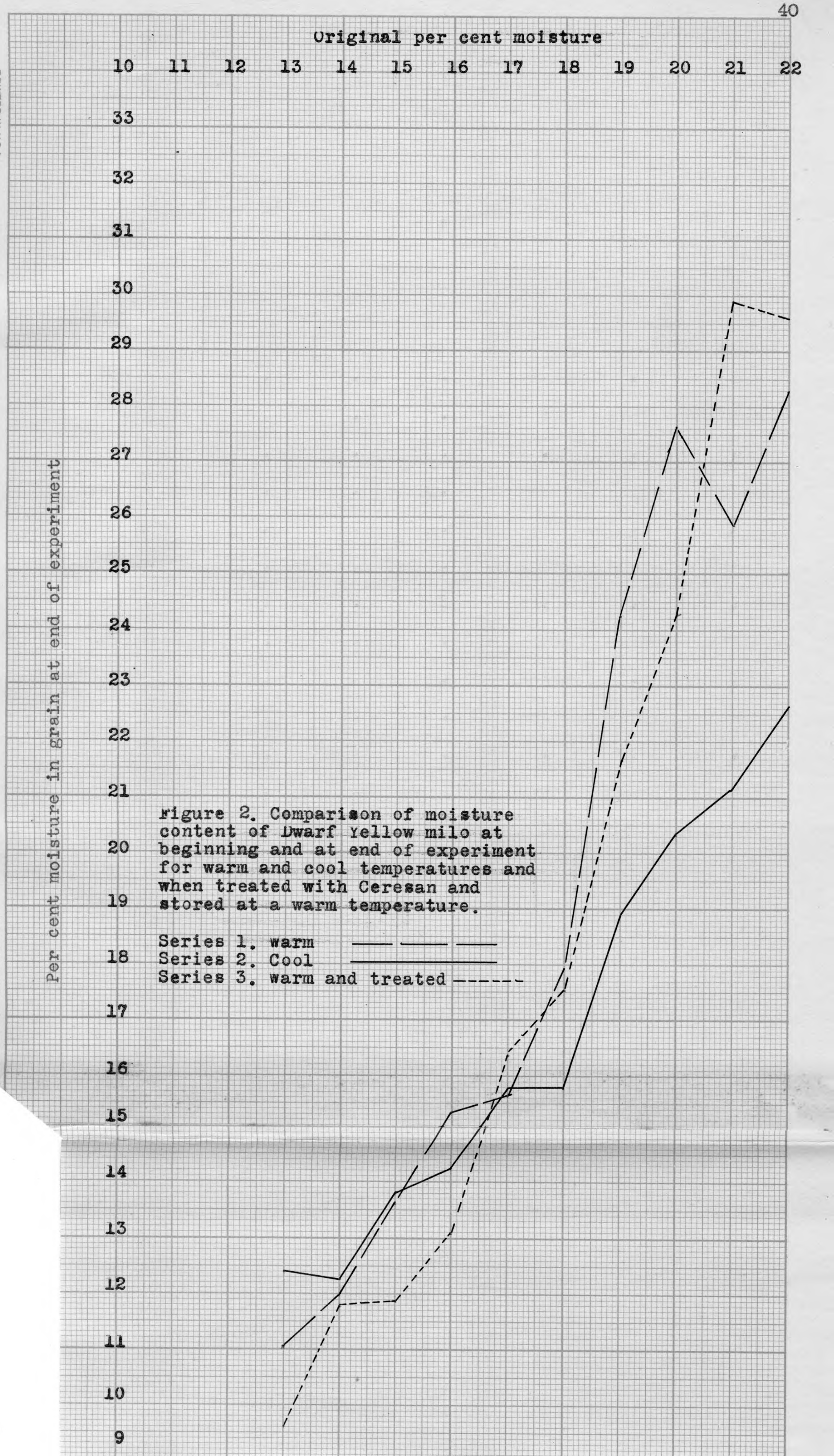


Figure 2. Comparison of moisture content of Dwarf Yellow milo at beginning and at end of experiment for warm and cool temperatures and when treated with Ceresan and stored at a warm temperature.

Table V. Kafir. Part 1. Summary of moisture content at end of second experiment.

Moisture Content Per Cent	Series 1 Warm	Series 2 Cool	Series 3 Warm Treated	Series 4 Warm Sealed	Series 5A Warm Removed 4 Weeks	Series 5B Warm Removed 2 Weeks
10	8.23	10.33	8.84	-----	8.87	9.58
11	10.13	11.12	11.40	-----	-----	-----
12	10.81	12.02	10.96	9.80	11.23	11.19
13	12.20	13.27	12.20	-----	-----	-----
14	12.35	13.64	13.11	-----	13.71	14.53
15	14.78	13.40	14.48	-----	-----	-----
16	16.16	16.04	15.48	13.86	16.61	16.64
17	19.16	16.80	18.24	-----	-----	-----
18	24.21	18.78	19.18	-----	21.13	18.78
19	22.10	22.68	22.17	-----	-----	-----
20	24.66	23.93	24.86	18.14	25.43	21.85
21	25.13	24.52	24.82	-----	-----	-----
22	30.19	24.72	28.26	20.02	27.86	22.70

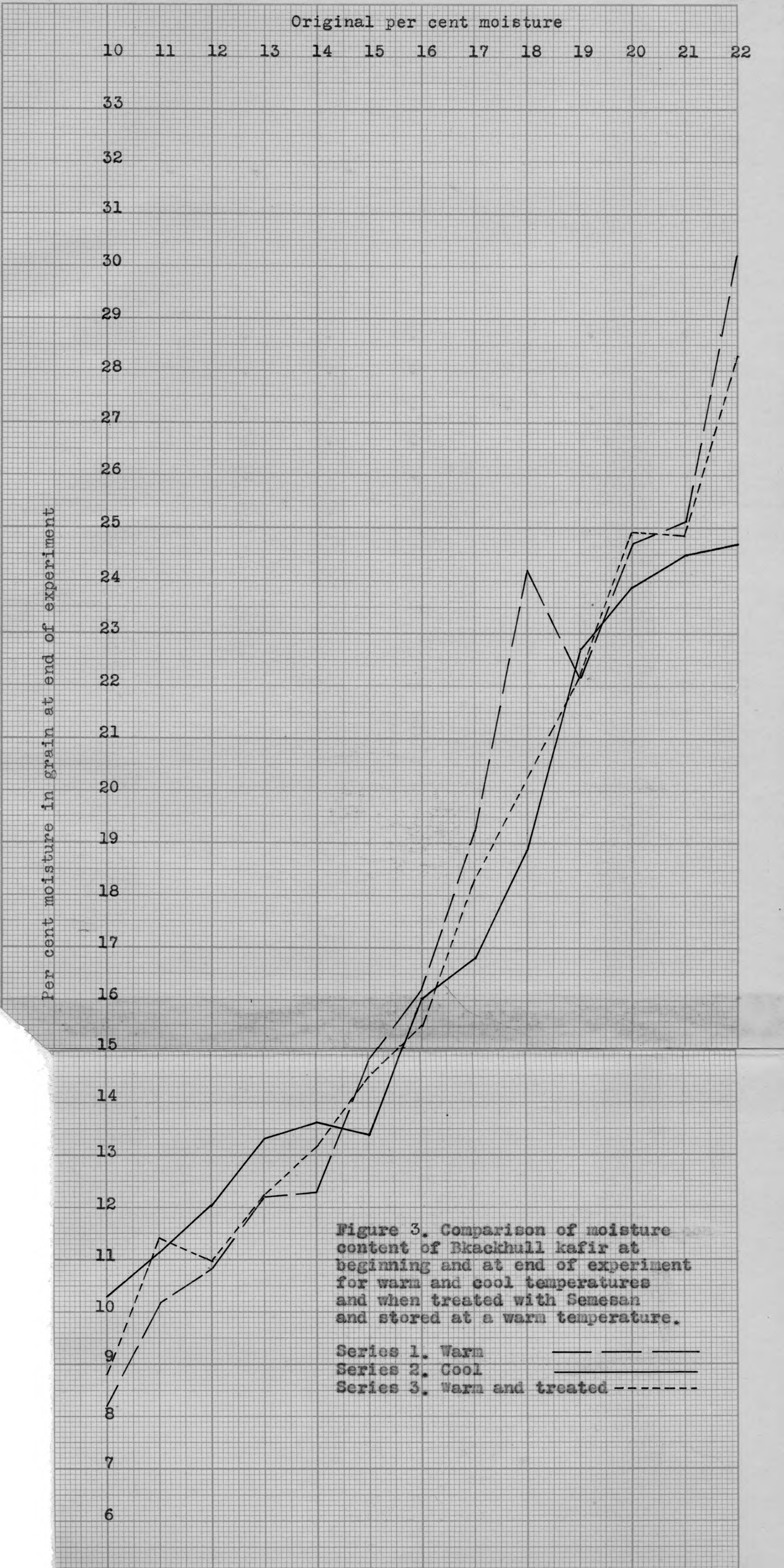


Figure 3. Comparison of moisture content of Bkackhull kafir at beginning and at end of experiment for warm and cool temperatures and when treated with Semesan and stored at a warm temperature.

Table VI. Milo. Part 1. Summary of moisture content at end of second experiment.

Moisture Content Per Cent	Series 1 Warm	Series 2 Cool	Series 3 Warm Treated	Series 4 Warm Sealed	Series 5A Warm Removed 4 Weeks	Series 5B Warm Removed 2 Weeks
10	6.38	11.10	7.28	-----	9.84	9.58
11	7.63	12.69	9.40	-----	-----	-----
12	8.51	13.98	10.22	9.40	11.61	10.94
13	9.73	14.84	10.49	-----	-----	-----
14	11.21	16.05	11.75	-----	13.51	13.10
15	12.72	17.47	12.91	-----	-----	-----
16	14.58	18.98	14.04	13.23	15.98	15.67
17	16.96	20.06	18.86	-----	-----	-----
18	19.05	21.13	19.01	-----	21.79	19.43
19	21.14	23.67	20.80	-----	-----	-----
20	23.07	27.70	21.50	17.05	22.41	19.80
21	23.62	30.53	25.43	-----	-----	-----
22	24.93	27.42	25.32	18.75	27.80	26.13

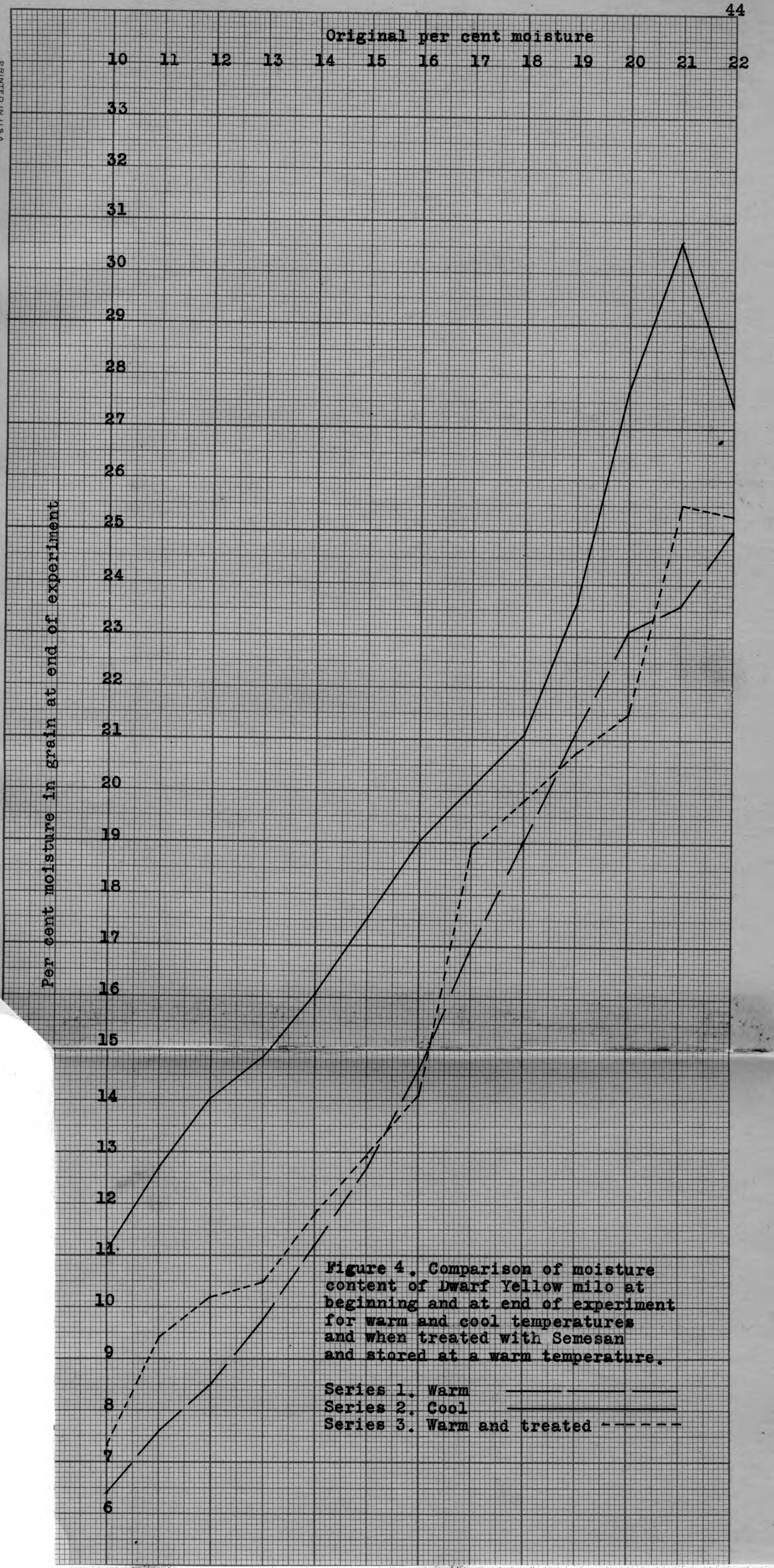


Figure 4. Comparison of moisture content of Dwarf Yellow milo at beginning and at end of experiment for warm and cool temperatures and when treated with Semesan and stored at a warm temperature.

Series 1. Warm
Series 2. Cool
Series 3. Warm and treated

Temperature

Temperature is always a factor to be considered in storing grain containing high moisture. Kafir and milo when stored with a high moisture content may keep safely through the cold weather but as soon as there is a rapid rise in temperature for a few days there is danger of heating. It may happen so quickly that much grain is damaged before its heating condition is observed.

A high temperature increases respirational activity of the grain. Bailey and Gurjar (10) found that about 55 degrees C. (131 degrees F.) was the optimum temperature for respirational activity of wheat. Coleman, Rothgeb, and Fellows (18) found that the rate of respiration of milo was about twice as great at 37.8 degrees C. as at 27.8 degrees C.

The decided influence of temperature on germination in these experiments is given in Table VII and Figure 5, which showed that kafir in Series 2 of the first experiment with a temperature 13.5 degrees C. (24.3 degrees F.) lower than Series 1 and 3, had a much higher viability and that the power of germination was even carried into the highest moisture range. This was also shown for milo in a lesser degree in Table VIII and Figure 6.

In the first experiment there was a consistent difference in moisture content at the end of the experiment due to the effect of the temperature. By consulting Table III and Figure 1 for kafir, and Table IV and Figure 2 for milo, these differences easily can be observed. In Series 2, the cool series, there is a consistently higher moisture content in the lower moisture range and a consistently lower moisture content in the higher moisture range in both kafir and milo. In this series the amount of moisture in the samples containing the maximum of 22 per cent original moisture, had increased less than one per cent, while in Series 1 and 3, the warm series, the moisture had increased from six to nine per cent.

The differences during the second experiment were similar but less pronounced for kafir, while milo gave a reverse result in the higher moisture range of the cool series. The smaller differences in moisture may be explained by the smaller differences in temperature.

Germination

Examination of the literature shows that viability of seeds is affected by many things of which age, moisture, and temperature appear to be the major factors.

Table VII and Figure 5 show the germination of kafir in the first experiment. This table shows an average germination in Series 2, stored at an average temperature of 33.2 degrees C. (91.7 degrees F.) much higher than either Series 1 or Series 3, stored at an average temperature of 19.7 degrees C. (67.4 degrees F.). Series 3 which was treated with Ceresan had a slightly higher germination than the untreated grain stored at the same temperature, except when the moisture content was high where there was a slight difference in favor of the untreated seed.

Six samples of kafir containing the same amount of moisture had an average germination at the end of the first experiment of 79 per cent when stored at the cool temperature, 37 per cent for untreated grain and 49 for treated grain stored at the warm temperature.

The exclusion of air had a slightly harmful effect on germination of kafir containing high moisture as shown in Series 4, which was sealed and stored at the warm temperature. Milo showed the same trend in viability as kafir when subjected to the same conditions, as is shown by Table VIII and Figure 6. The germination was much higher in the cool series in the grain containing high moisture.

The average germination for the samples of milo containing the same amount of moisture was 57 per cent for the cool series as compared with 51 per cent for the untreated grain and 47 per cent for the treated grain stored at warm temperatures. In this instance the treated grain had a slightly lower germination than the untreated. There was a decided difference in the sealed series and the viability of the milo was more affected than kafir by excluding air. The germination at low moisture content was greatly reduced, the grain containing 16 per cent moisture germinated only 2 per cent and at higher moisture contents the seed had lost all germinative power.

The germination of kafir at the beginning of the first experiment was 80 per cent and at the beginning of the second experiment was only 61 per cent for the same lot. No doubt the rather large amount of immature grain was largely responsible for this decline in viability. It will be seen by an examination of the tabular data that some of the samples germinated higher than 61 per cent and this was probably due to the small number of samples originally tested.

In the second experiment a decided decline in viability began at 13 and 14 per cent moisture. There was not a consistent difference between Series 2 and Series 1 and 3, due to the fact there was so little difference in the temperature. The outstanding feature of the second experiment as shown in Tables IX and X and Figures 7 and 8 is the low germination in the samples from 14 to 18 per cent moisture. The grain in Series 5B at the end of two weeks had a higher germination than in Series 5A at the end of four weeks, and there was a further decline at the end of six weeks in the grain containing 14, 16, and 18 per cent moisture. All grain containing 20 per cent or more moisture was dead at the end of two weeks.

Table VII. Kafir. Part 1. Summary of average per cent germination at the end of the first experiment.

Moisture Content Per Cent	Series 1 Warm	Series 2 Cool	Series 3 Warm Treated	Series 4 Warm Sealed	Series 5A Warm Removed 4 Weeks	Series 5B Warm Removed 2 Weeks
	35	82	64	--	56	67
	39	81	48	--	--	--
	33	83	49	44	68	58
	38	79	49	--	--	--
	40	74	35	--	51	57
	37	76	49	--	--	--
16	46	81	34	40	47	51
17	37	61	35	--	--	--
18	26	54	8	--	37	56
19	8	49	5	--	--	--
20	7	47	3	0	25	29
21	0	32	2	--	--	--
22	0	24	0	0	1	8

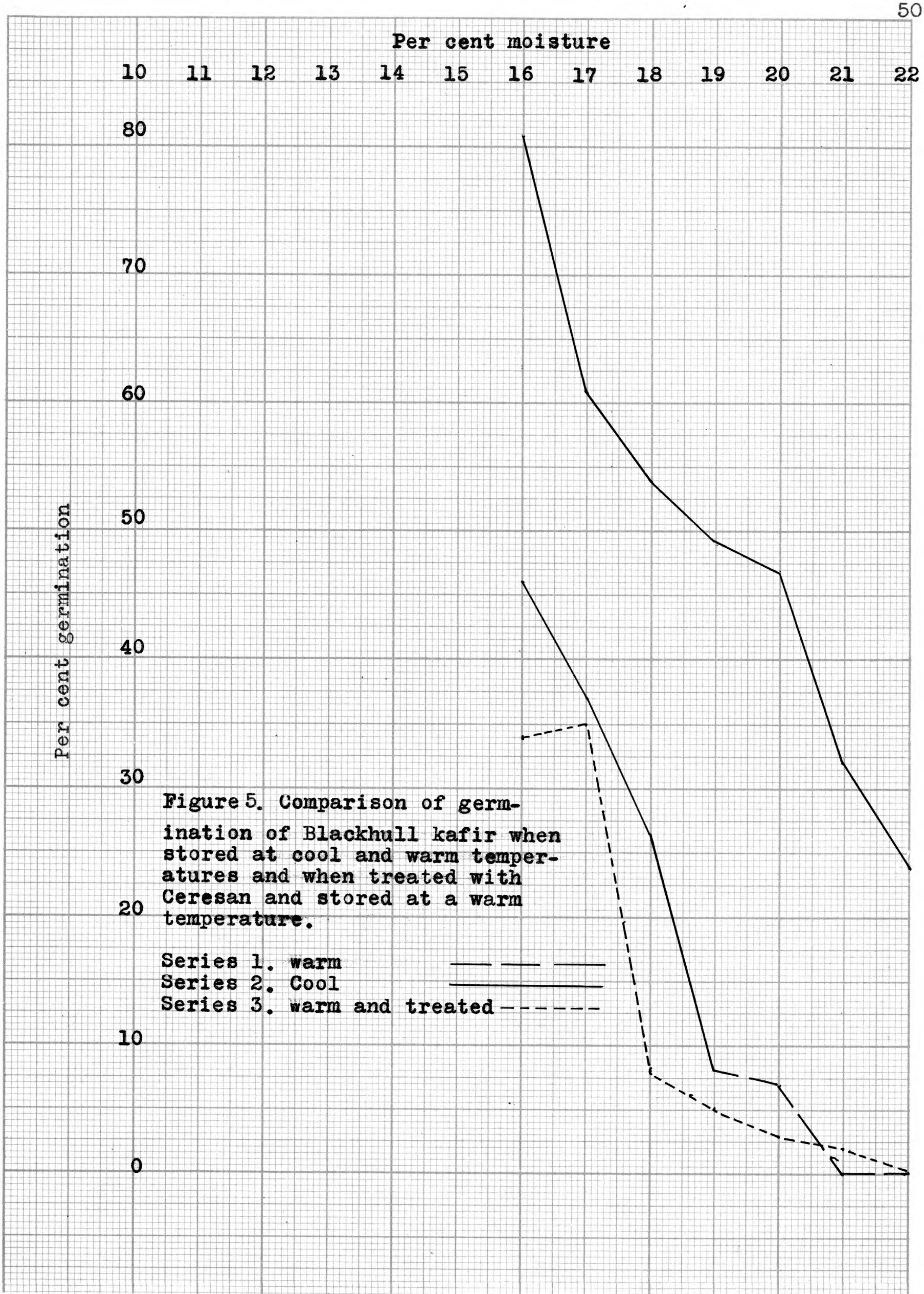


Figure 5. Comparison of germination of Blackhull kafir when stored at cool and warm temperatures and when treated with Ceresan and stored at a warm temperature.

Table VIII. Milo. Part 1. Summary of average per cent germination at end of first experiment.

Moisture Content Per Cent	Series 1 Warm	Series 2 Cool	Series 3 Warm Treated	Series 4 Warm Sealed	Series 5A Warm Removed 4 Weeks	Series 5B Warm Removed 2 Weeks
	46	47	42	--	51	57
	57	58	52	--	--	--
	52	66	48	27	48	54
13	64	46	52	--	--	--
14	--	59	63	--	46	55
15	37	67	43	--	--	--
16	9	50	12	2	19	26
17	8	28	7	--	--	--
18	4	15	2	--	10	12
19	5	15	4	--	--	--
20	0	15	0	0	11	7
21	0	7	0	--	--	--
22	0	0	0	0	0	1

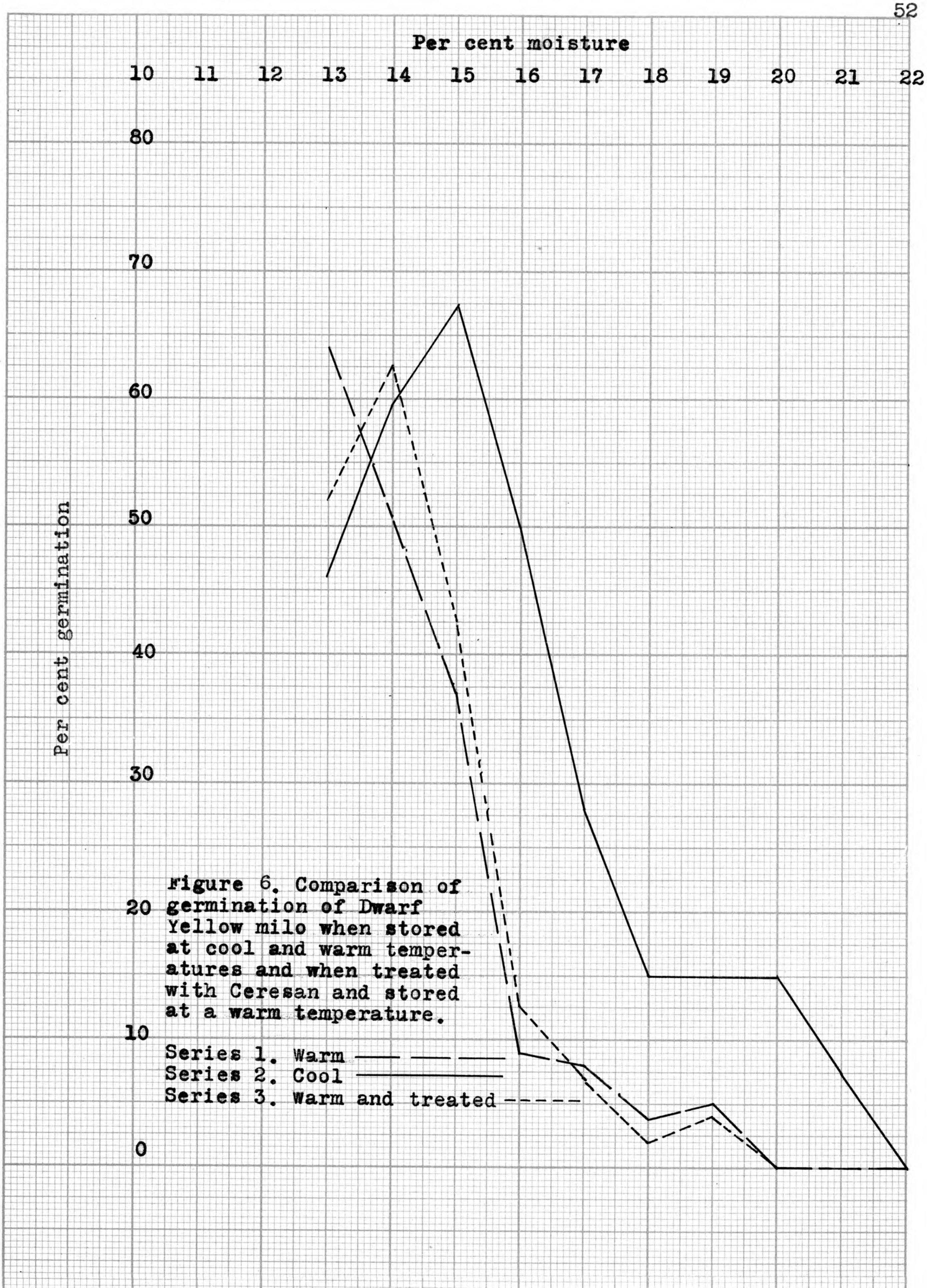


Figure 6. Comparison of germination of Dwarf Yellow milo when stored at cool and warm temperatures and when treated with Ceresan and stored at a warm temperature.

Table IX. Kafir. Part 1. Summary of average per cent germination at end of second experiment.

Moisture Content Per Cent	Series 1 Warm	Series 2 Cool	Series 3 Warm Treated	Series 4 Warm Sealed	Series 5A Warm Removed 4 Weeks	Series 5B Warm Removed 2 Weeks
10	66	71	73	--	70	70
11	61	60	71	--	--	--
12	44	64	64	43	51	50
13	14	29	28	--	--	--
14	4	11	2	--	5	24
15	1	4	0	--	--	--
16	0	4	0	0	22	38
17	2	7	0	--	--	--
18	0	4	0	--	2	18
19	0	$\frac{1}{2}$	0	--	--	--
20	0	0	0	0	0	0
21	0	0	0	--	--	--
22	0	0	0	0	0	0

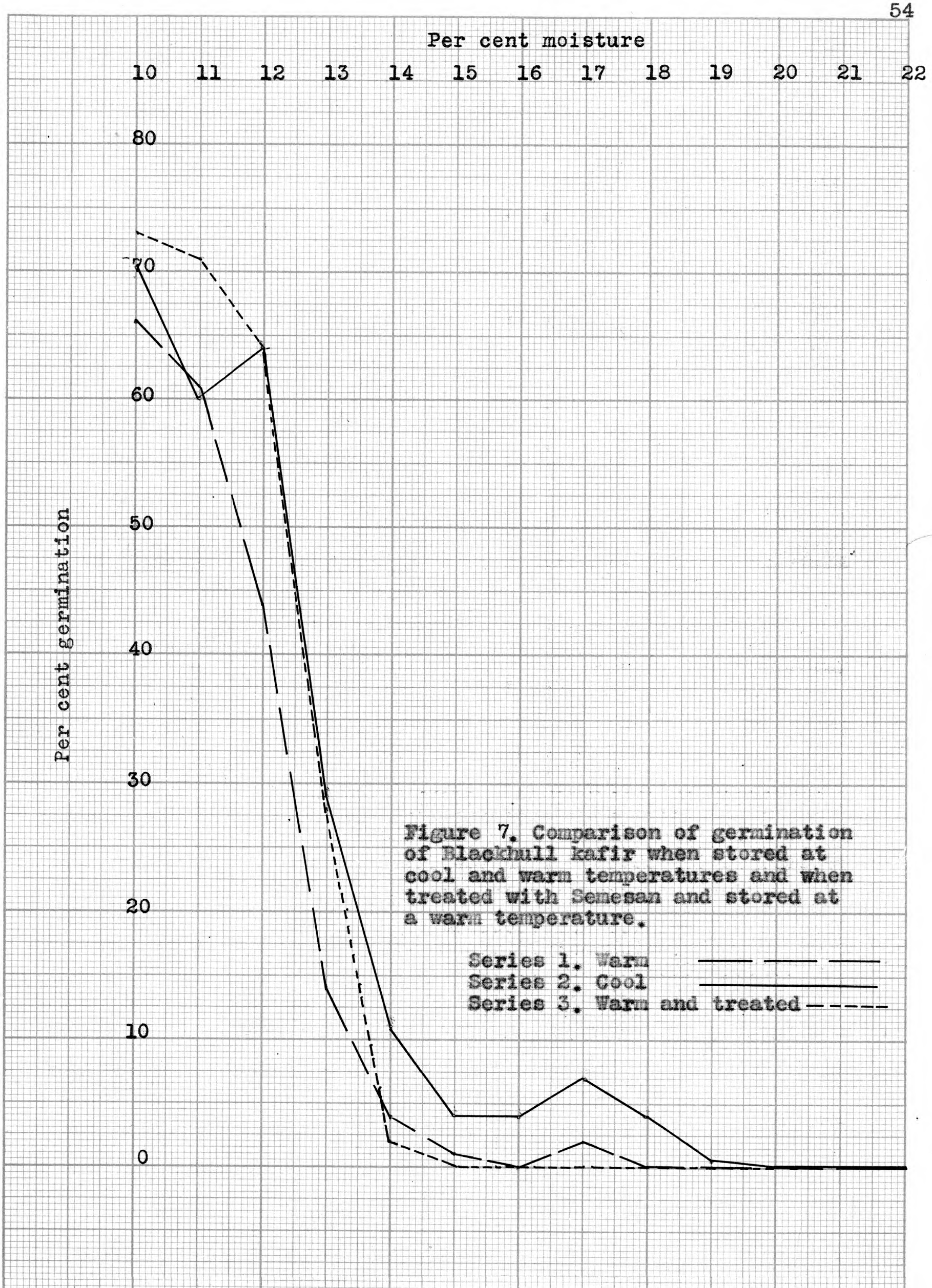


Figure 7. Comparison of germination of Blackhull kafir when stored at cool and warm temperatures and when treated with Semesan and stored at a warm temperature.

Table X. Milo. Part 1. Summary of average per cent germination at end of second experiment.

Moisture Content Per Cent	Series 1 Warm	Series 2 Cool	Series 3 Warm Treated	Series 4 Warm Sealed	Series 5A Warm Removed 4 Weeks	Series 5B Warm Removed 2 Weeks
10	84	80	79	--	78	72
11	73	76	77	--	--	--
12	67	71	69	40	70	67
13	36	42	32	--	--	--
14	2	11	2	--	0	17
15	1	3	½	--	--	--
16	0	4	0	0	9	13
17	0	½	0	--	--	--
18	0	0	0	--	0	20
19	0	0	0	--	--	--
20	0	0	0	0	0	0
21	0	0	0	--	--	--
22	0	0	0	0	0	0

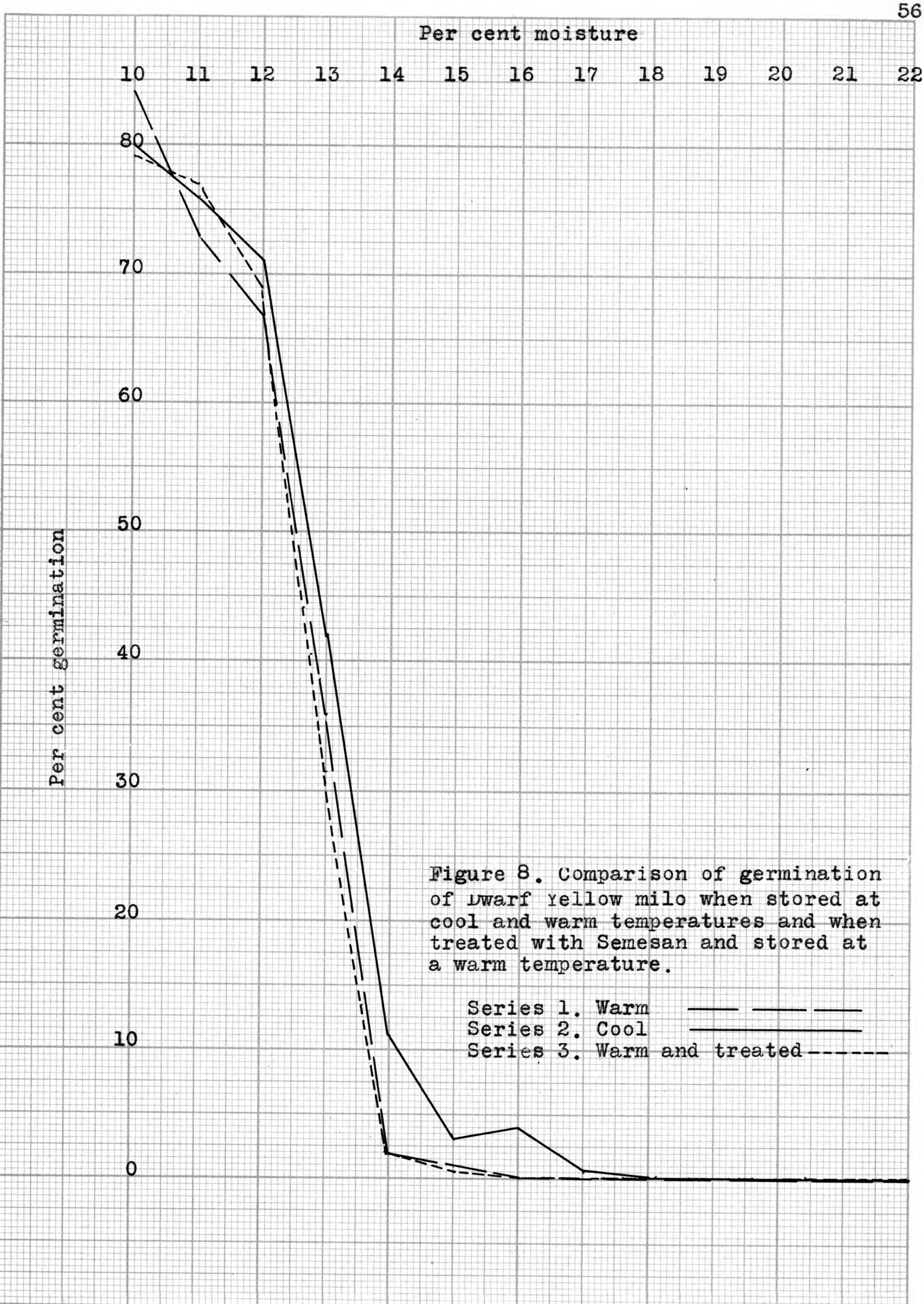


Figure 8. Comparison of germination of Dwarf Yellow milo when stored at cool and warm temperatures and when treated with Semesan and stored at a warm temperature.

Molds

Mold spores appear always to be present on stored grain. Their growth and development occur only when there are favorable conditions, such as optimum temperature and moisture. The presence of molds affect practically all factors which determine the condition and grade of commercial grain. The presence of a small amount of mold will impart a musty odor to the grain, which eliminates it from any of the regular market grades and places it in sample grade. According to the official grades for grain sorghums, "Sample grade shall include grain sorghums of any class or sub-class which do not come within the requirements of any of the grades from No. 1 to No. 4, inclusive; or ..... which are musty, or sour, or heating, or hot;....."

Conn (19) defines molds as fungi of considerable size and visible to the naked eye, but not forming a scientific group. They are at first usually fluffy masses, usually white, or may become blue, green, brown, black, or red, as they become older and form spores. They develop in a few days under optimum conditions.

The most commonly observed molds on grain are various species of _Aspergillus_, _Penicillium_, _Rhizopus_, and _Fusarium_ but many others may frequently be found. Thom and Church

(64) recognize 66 species of *Aspergillus* and over 600 species of *Penicillium* (65). Henrici (28) says 265 species of molds have been isolated from the soil and names them in the order of the frequency in which they occur as *Zygorrhynchus*, *Penicillium*, *Trichoderma*, *Fusarium* *Mucor*, *Aspergillus*, and *Rhizopus*. Identification is difficult and laborious except by an experienced mycologist.

The same kind of mold spores may be found growing on many different substrates. Hurd (30) states that *Penicillium* and *Rhizopus* are the two omnipresent molds which may occur in blotter germinations. Gilman and Barron (25) found *A. flavus*, *A. niger* and *A. fumigatus* commonly present on oats, wheat, and barley. Read (49) reports that Herter and Fornet found these molds growing on bread: *A. indulous*, *A. glaucus*, *A. niger*, *A. funigatus*, *A. glaucum*, and others.

The molds found growing on kafir and milo in these experiments were identified by Dr. C. L. Lefebvre of the Department of Botany, Kansas State College, as various species of Aspergilli, with *A. niger* and *A. flavus* predominating in the warm series, and *Cephalothecum roseum*, Cda. predominating under lower temperature.

In the first experiment the mold began to be observable at the end of one week in all samples of kafir stored at warm temperatures and containing 18 per cent and more moisture. The amount of mold growth increased as the moisture content increased. Samples containing 17 per cent and less moisture remained in good condition. In the cool series the mold was only slightly observable. The condition of the milo was, in general, similar to that of the kafir, except mold development frequently began at about 2 per cent lower moisture content. During the second week the mold seemed to develop quite rapidly in the warm series but slowly at cool temperatures.

The mold development on milo at the end of two weeks is shown in Figure 9, at the end of four weeks in Figure 10, and at the end of six weeks in Figure 11.

It can be observed in Figure 9 that in the sample at the right containing 22 per cent moisture, the mold growth was so rapid on the top surface of the grain it formed a heavy mass of mold which almost sealed the lower portion of grain away from the free air coming through the opening in the lid of the container. The next container to the left, containing 20 per cent moisture, had mold extending more uniformly about two-thirds to the bottom of the grain. The next container with 18 per cent moisture had comparatively little mold development and it was distributed more evenly from top to bottom of the grain. There was much variation in mold growth and distribution in the different containers,

Figure 9. Series 5B. Milo. Mold development at end of two weeks. Moisture content increases from left to right.

Figure 10. Series 5A. Milo. Mold development at end of four weeks. Moisture content increases from left to right.

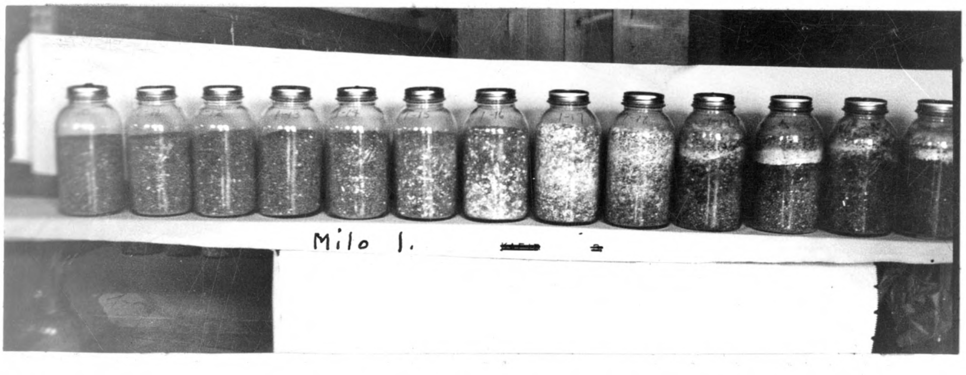


Figure 11. Series 1. Milo. Mold development at end of six weeks. Moisture content increases from left to right.

but in general the growth was very similar under like conditions. Series 4, which was sealed, had no observable mold growth but much evidence of fermentation in grain of 20 and 22 per cent moisture content.

Milo appears to be more susceptible to mold attack than kafir. Figure 12 shows three samples of kafir containing 15, 16, and 17 per cent of moisture and three samples of milo containing like amounts of moisture.

Figure 12. Comparison of mold growth on kafir and milo under similar conditions. Moisture content increases from left to right.

The samples of milo, particularly the middle one containing 16 per cent moisture show greater amount of mold growth than kafir. Milo has a softer grain and is more subject to seed coat injury during threshing and handling, which probably permits an earlier and more vigorous attack of mold spores.

Series 3 was treated with Ceresan in the first experiment and with Semesan in the second. The recommended quantity of each was mixed with the grain in a barrel mixer which was turned for two minutes. The treated grain was then placed in a metal container, covered, and left for twenty-four hours before being used in the experiment.

Both of these mercuric dusts seemed to retard all mold growth for a few days and certain molds appeared to be retarded more than others. Aspergillus niger was one of the first to appear and was the dominant mold in the treated grain. Other molds were much delayed except in the higher moisture samples where white and greenish-yellow mold soon began to appear and become dominant. When Ceresan was used in the first experiment, black mold A. niger, began first to appear under high moisture conditions and as time progressed the black mold appeared at lower moisture contents. Figure 13 shows milo in the treated series of the first experiment.

Figure 13. Aspergillus niger appearing in milo in the first experiment. Moisture content increases from left to right.

A slightly black condition can be seen in the milo with

16 per cent moisture. The samples containing 17, 18, and 19 per cents moisture contained so many black spores that the whole inside of the container became clouded upon shaking. The spores were first observed when the containers were shaken. At first the grain would appear clear but after being agitated the black spores clouded the entire mass of grain as well as the space containing air. In the samples of 20 per cent moisture, white and other molds had grown to the extent that the black was largely overcome. In the samples containing 21 and 22 per cent moisture, there was just a small proportion of black mold showing, other molds having become dominant. When Semesan was used in Series 3 in the second experiment, the results were somewhat different.. Semesan like Ceresan had a retarding effect on all mold growth. The black clouds of spores which developed when Ceresan was used did not appear when Semesan was used, but the black molds appeared more like they did in the higher moisture samples of the first experiment. In neither instance did these mercuric dusts as used in these experiments, prove effective in preventing mold growth. They had a slight inhibiting effect on A. niger, and a greater inhibiting effect on other molds. Such treatment may be of some value in delaying mold growth on seed sown in the soil so germination can take place before being hindered by the molds. The behavior of kafir under like circumstances

was similar to that of milo.

Insects

No weevil or insect infestation occurred during the first experiment. During the second experiment insects appeared in some of the samples in Part 2 and a discussion of their activities will be found there.

Weight per Bushel

It is well known that an increase in moisture content decreases the weight per bushel of grain. Kafir and milo, going out of condition and becoming moldy, declined rapidly in weight per measured bushel. This may be explained by the swelling of the grain due to the adsorption of water by the hydrophilic colloids and to the loss of carbohydrate material consumed in the process of respiration and by the parasitic fungi. The rapid decline of weight per bushel as shown by Table XI and Figure 14 for kafir, and Table XII and Figure 15 for milo in the first experiment, began when the grain had reached a condition where it became moldy. It was difficult to obtain satisfactory samples for the weight per bushel test of grain with high moisture because it became badly caked and lumpy and had to be broken apart to remove it from the containers. Therefore the results of this test in the high moisture range lacked uniformity. In Series 4 where mold development was prevented by anaerobic conditions the weight per bushel declined much less in the high moisture samples than where the grain had an available oxygen supply and molds developed freely. In grain sorghums containing 16 per cent or less moisture, the weight per bushel in most instances was lower in the sealed containers as the grain retained the moisture with very little loss throughout the duration of the experiment. However the actual moisture content did not fully account for the difference. There seemed to be less change in the condition of the grain in the sealed series which probably accounted in part for the lower weight of the grain in the low moisture range.

The temperature at which the grain is maintained affects its biological activity, and the activity of the fungi which grow upon it. In general, the higher temperature results in more favorable conditions for biological activity of the grain and the parasitic growth. In comparing the grain which was maintained at a cool temperature with that stored at a warm temperature, there generally was a higher weight per bushel in the cool series. In the second experiment this difference is not as pronounced as the differences in temperature were not as great. It will be seen by the examination of the data of the second experiment that the weight per bushel may not be lowest in the samples containing the highest amount of moisture as is generally true in the first experiment. An explanation of how the samples were handled during the two experiments will aid in understanding these differences. In the first experiment the added water was not as thoroughly mixed with the grain during the two days immediately after the water was added. In the warm series where excess moisture was present, the germination began so rapidly that the grain began to mat together near the bottom of the container. A greater amount of moisture accumulated near the bottom of the mass of grain to accelerate the activity. It was found necessary to open some of the containers and again mix the grain thoroughly. The grain in the first experiment was thoroughly mixed each week by shaking and rotating the containers at the time of weighing. This kept the molds from forming a solid covering over the top of the grain, or if it did form, it was broken by the mixing each week.

In the second experiment the grain was mixed very thoroughly several times each day for the first four days in an attempt to have uniform moisture conditions in the mass of grain in each sample. It was found that the transfer of moisture from wet to dry grain in bulk, was a slow process and required much attention and frequent mixing. This slow equalization of moisture is in agreement with the findings of Humphries and Hurst (29). After the grain was thoroughly mixed during the first week of the experiment and at the weighing period at the end of the first week, no attempt was made to mix the grain during the remainder of the experiment. This permitted the mold growth in the high moisture samples to form a cover over the top of the grain which in some instances formed an air-tight or near air-tight seal. Thus it appeared that free oxygen was eliminated, or nearly so, and the mold development was very much retarded in the lower half of the containers. In some instances the grain in the lower part of the containers appeared almost free from mold attack and in apparent good condition. In making the test weight, the proportion of this grain affected the results and had a determining influence on this test.

Generally the mold growth was much more evenly distributed throughout the lower half of the containers containing 17 or 18 per cent moisture than in the samples containing 20 or 22 per cent moisture. In the samples which contained 17 or 18 per cent moisture the early development of the mold was not so rapid and continued to a greater depth in the mass of grain before the top became sealed off by the more rapid growth, as was the case in the higher moisture range. This is excellently shown in Plates I, II and III.

Table XI. Kafir. Part 1. Summary of weight per bushel at end of first experiment.

Moisture Content Per Cent	Series 1 Warm	Series 2 Cool	Series 3 Warm Treated	Series 4 Warm Sealed	Series 5A Warm Removed 4 Weeks	Series 5B Warm Removed 2 Weeks
[illegible]	54.8	55.3	54.8	----	54.9	55.0
[illegible]	54.7	55.5	55.5	----	----	----
[illegible]	54.5	55.3	55.2	53.5	55.0	55.5
[illegible]	54.4	55.2	55.3	----	----	----
[illegible]	54.4	55.2	55.4	----	55.4	55.4
[illegible]	54.4	55.4	55.3	----	----	----
16	54.2	53.6	55.3	54.5	55.4	54.8
17	54.1	54.9	54.9	----	----	----
18	53.4	54.8	53.6	----	53.6	54.1
19	49.4	54.3	51.5	----	----	----
20	45.8	52.6	46.5	52.5	50.5	50.8
21	44.4	48.3	46.0	----	----	----
22	43.4	45.5	45.7	51.2	46.2	42.7

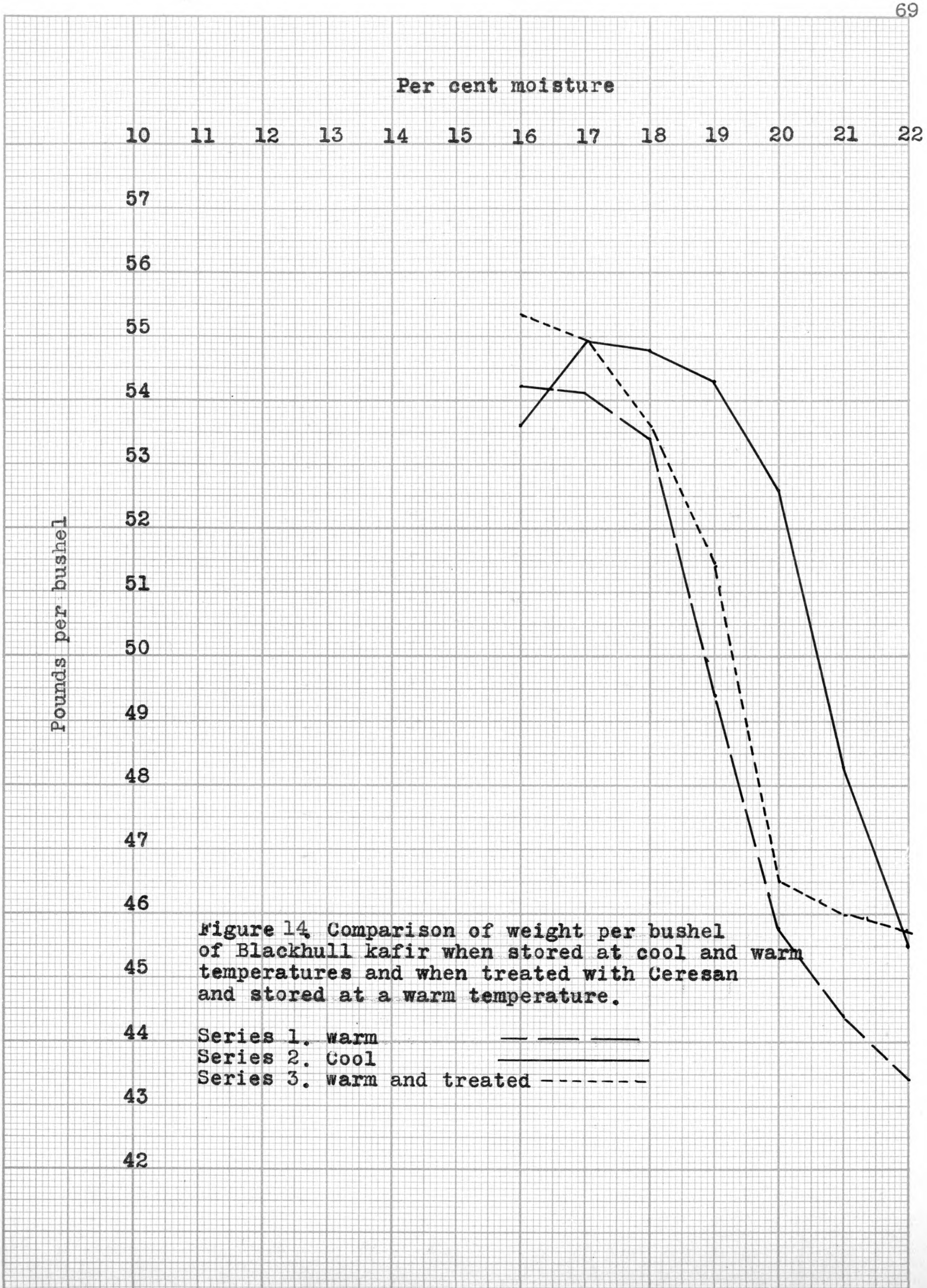


Figure 14. Comparison of weight per bushel of Blackhull kafir when stored at cool and warm temperatures and when treated with Ceresan and stored at a warm temperature.

Series 1. warm — — —
Series 2. Cool ————
Series 3. warm and treated - - - - - - -

Table XII. Milo. Part 1. Summary of weight per bushel at end of first experiment.

Moisture Content Per Cent	Series 1 Warm	Series 2 Cool	Series 3 Warm Treated	Series 4 Warm Sealed	Series 5A Warm Removed 4 Weeks	Series 5B Warm Removed 2 Weeks
[illegible]	56.1	56.3	56.0	----	56.2	56.1
[illegible]	56.2	56.3	56.4	----	----	----
[illegible]	56.1	56.2	56.2	56.0	56.2	56.0
13	56.0	56.3	56.2	----	----	----
14	55.9	56.2	56.4	----	56.1	56.1
15	55.8	56.1	56.2	----	----	----
16	54.6	55.4	55.7	54.7	54.7	54.8
17	53.5	54.8	53.8	----	----	----
18	51.9	54.1	50.5	----	52.5	52.4
19	45.7	52.4	46.1	----	----	----
20	45.0	50.8	44.2	52.6	49.5	50.0
21	44.6	49.4	44.2	----	----	----
22	45.3	46.0	42.5	51.7	47.2	41.5

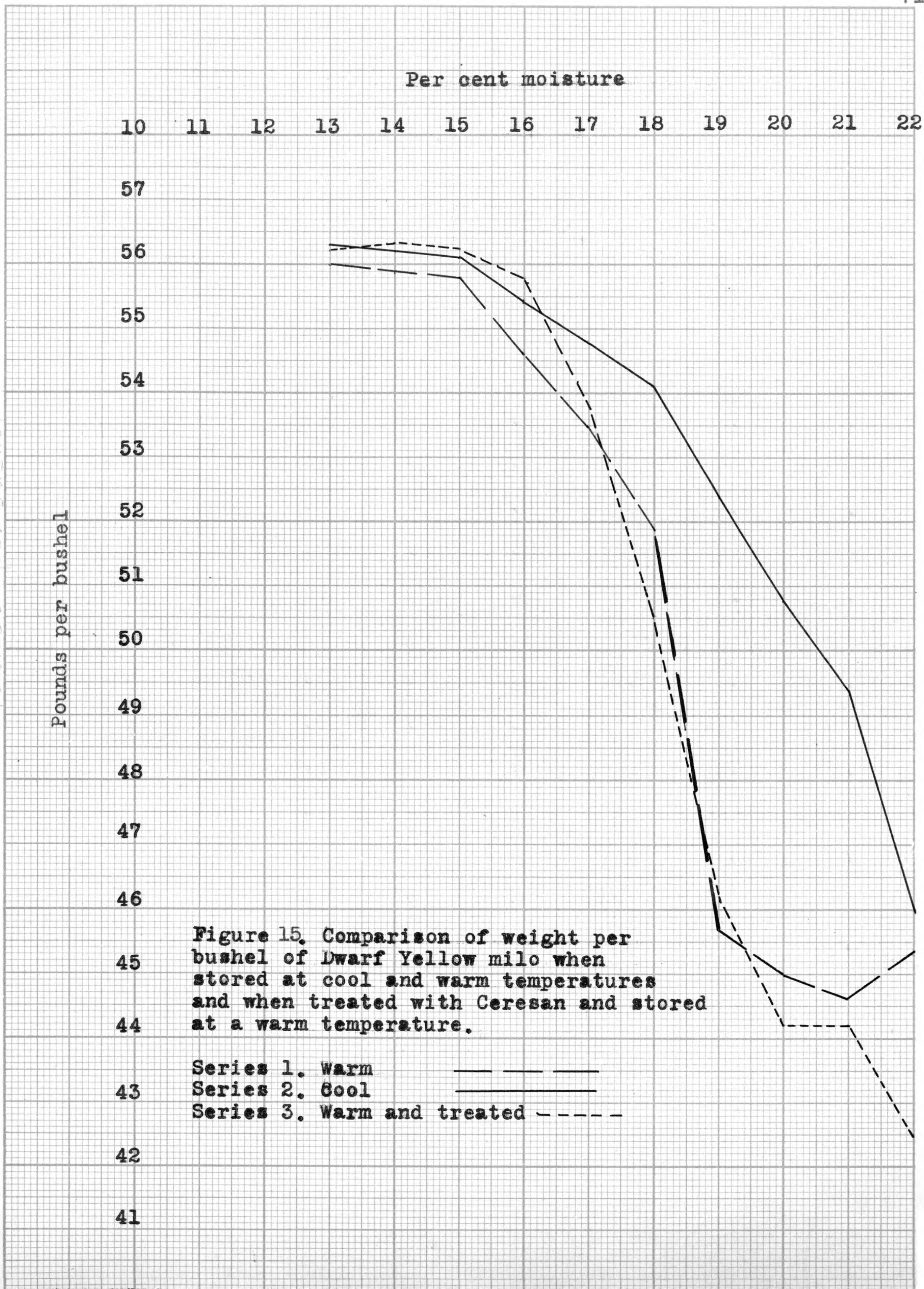


Figure 15. Comparison of weight per bushel of Dwarf Yellow milo when stored at cool and warm temperatures and when treated with Ceresan and stored at a warm temperature.

Table XIII. Kafir. Part 1. Summary of weight per bushel at end of second experiment.

Moisture Content Per Cent	Series 1 Warm	Series 2 Cool	Series 3 Warm Treated	Series 4 Warm Sealed	Series 5A Warm Removed 4 Weeks	Series 5B Warm Removed 2 Weeks
10	55.8	55.5	54.6	----	55.4	55.5
11	55.6	55.4	54.7	----	----	----
12	55.4	55.1	54.6	55.2	55.0	55.2
13	55.1	54.7	54.4	----	----	----
14	54.8	54.6	54.2	----	54.3	54.7
15	53.7	54.4	53.7	----	----	----
16	52.1	53.2	53.3	51.8	53.0	54.0
17	49.6	49.6	50.0	----	----	----
18	45.6	47.0	46.5	----	47.4	53.3
19	44.3	45.7	43.5	----	----	----
20	41.8	44.2	43.0	52.0	46.5	50.8
21	43.9	44.2	43.4	----	----	----
22	41.5	42.9	43.5	51.3	44.0	48.5

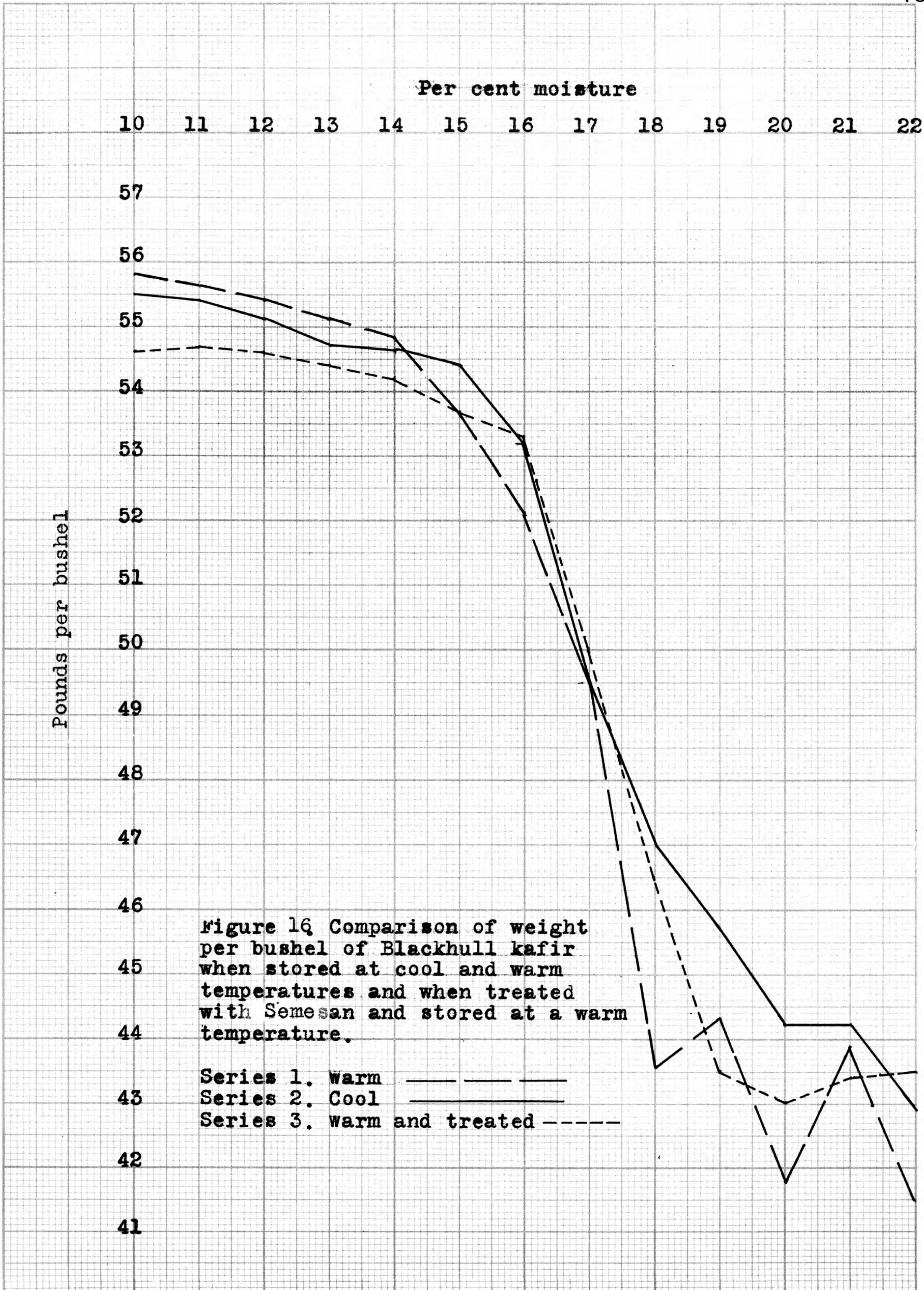


Figure 16 Comparison of weight per bushel of Blackhull kafir when stored at cool and warm temperatures and when treated with Semesan and stored at a warm temperature.

Table XIV. Milo. Part 1. Summary of weight per bushel at end of second experiment.

Moisture Content Per Cent	Series 1 Warm	Series 2 Cool	Series 3 Warm Treated	Series 4 Warm Sealed	Series 5A Warm Removed 4 Weeks	Series 5B Warm Removed 2 Weeks
10	57.1	57.1	56.5	----	57.1	57.4
11	57.1	57.1	56.5	----	----	----
12	56.8	56.7	56.0	56.5	56.6	56.8
13	56.2	56.2	55.9	----	----	----
14	55.0	54.8	55.7	----	55.3	55.9
15	52.2	53.5	54.8	----	----	----
16	46.3	48.1	53.7	55.1	50.4	54.6
17	43.2	46.1	44.5	----	----	----
18	43.8	44.9	43.9	----	45.6	51.2
19	44.2	45.1	44.6	----	----	----
20	42.3	44.8	44.3	53.0	44.5	48.6
21	43.3	43.3	45.2	----	----	----
22	43.4	45.8	44.4	52.4	44.0	49.4

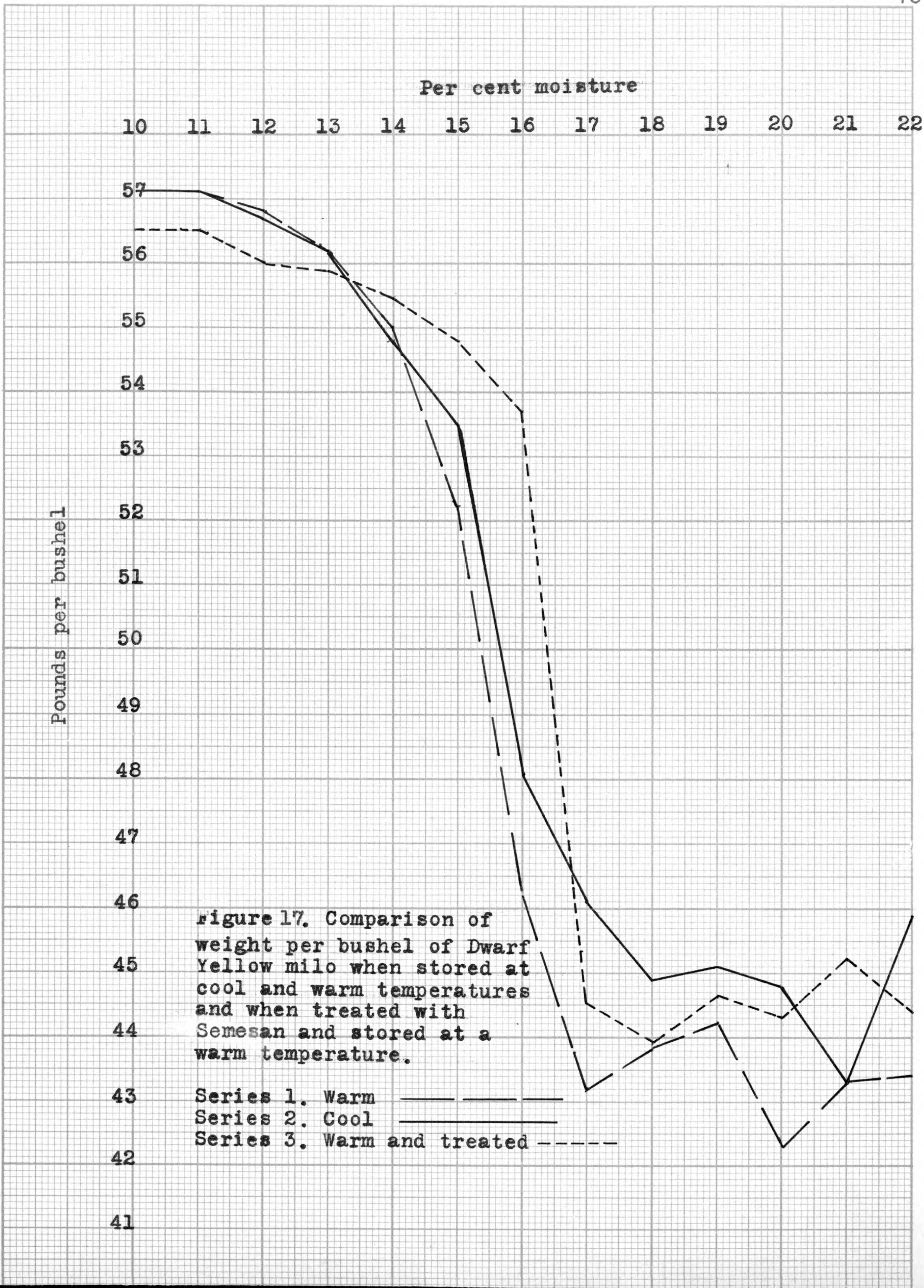


Figure 17. Comparison of weight per bushel of Dwarf Yellow milo when stored at cool and warm temperatures and when treated with Semesan and stored at a warm temperature.

Loss in Weight

The samples were weighed once each week, the weight recorded, and the loss in weight calculated. Table XV and Figure 18 show the loss in weight of kafir and Table XVI and Figure 19 show the loss in weight for milo during the first experiment. There is a consistent correlation between loss in weight when the warm and cool temperatures are compared. The loss in weight in Series 2, the cool series, is approximately one-third of the loss in the warm series, and this is true of both kafir and milo. The loss in weight in Series 5B, which was stored at a warm temperature and removed at the end of two weeks, was approximately equal to the loss in weight in Series 2, stored at a cool temperature for the full period of six weeks.

In the second experiment the loss in weight in the cool series approached the loss in weight in the warm series in approximate relationship to the two temperatures. Toward the end of the experiment the cool temperature so nearly approached the warm temperature that the difference in loss in weight is not significant. See Tables XVII and XVIII and Figures 20 and 21.

Loss in weight of a given volume of grain is usually attributed to reduction in moisture content. That may be largely true for grain with low moisture, but loss in weight as a rule is greater than the weight of the moisture lost. When molds are present there is normally a loss in weight but an increase in moisture content. This loss in weight may be largely attributed to the consumption of the carbohydrates by the processes of respiration of the grain and molds. The increase in moisture may likewise be attributed to the respirational activity and the reduction of the base weight because carbohydrates have been consumed. Normal respiration of the grain consumes carbohydrates in proportion to the amount of carbon dioxide given off. McGinnis (45) says that with Marquis wheat the formation of 100 grams of carbon dioxide will require 61.36 grams of carbohydrate material.

Table XV. Kafir. Part 1. Summary of loss in weight in per cent at the end of the first experiment.

Moisture Content Per Cent	Series 1 Warm	Series 2 Cool	Series 3 Warm Treated	Series 4 Warm Sealed	Series 5A Warm Removed 4 Weeks	Series 5B Warm Removed 2 Weeks
	1.21	.34	1.08	----	.84	.45
	1.26	.33	1.16	----	----	----
	1.32	.40	1.25	.13	.76	.41
	1.15	.39	1.16	----	----	----
	1.24	.36	1.04	----	.75	.37
	1.19	.40	1.18	----	----	----
16	1.17	.38	1.08	.06	.73	.59
17	1.16	.38	1.14	----	----	----
18	1.57	.51	1.30	----	1.08	.60
19	2.27	.63	1.41	----	----	----
20	3.04	.72	2.78	.34	1.84	1.16
21	4.39	1.01	3.82	----	----	----
22	4.69	1.47	3.85	.56	3.81	1.53

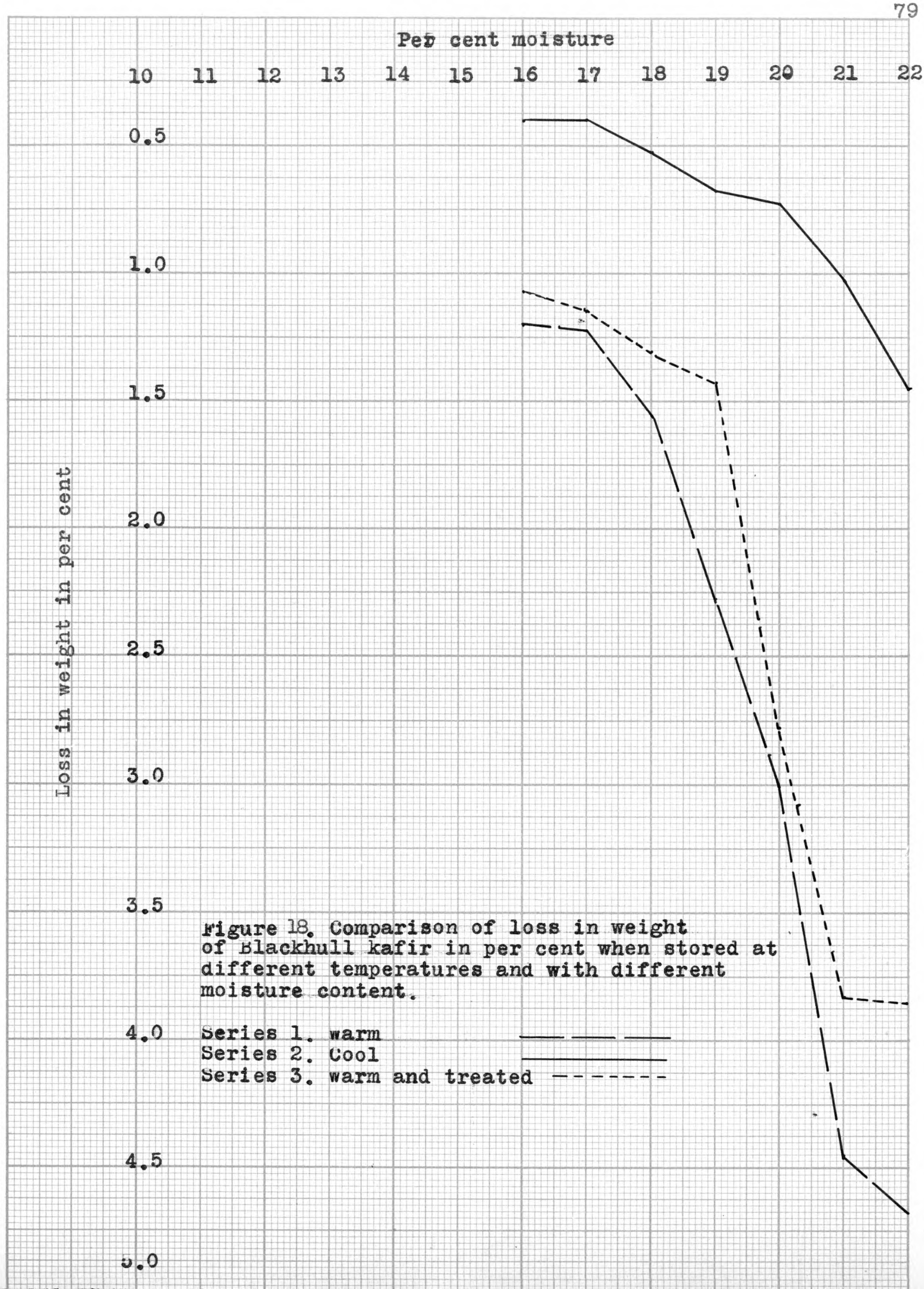


Figure 18. Comparison of loss in weight of Blackhull kafir in per cent when stored at different temperatures and with different moisture content.

Table XVI. Milo. Part 1. Summary of loss in weight in per cent at end of first experiment.

Moisture Content Per Cent	Series 1 Warm	Series 2 Cool	Series 3 Warm Treated	Series 4 Warm Sealed	Series 5A Warm Removed 4 Weeks	Series 5B Warm Removed 2 Weeks
	.68	.23	.75	---	.48	.26
	.82	.27	.75	---	---	---
	.72	.22	.67	.02	.52	.26
13	.72	.21	.79	---	---	---
14	.88	.27	.93	---	.62	.23
15	.95	.39	1.09	---	---	---
16	1.14	.40	1.19	.34	.85	.51
17	1.80	.46	1.36	---	---	---
18	2.03	.56	1.91	---	1.39	1.03
19	3.05	.83	2.54	---	---	---
20	3.92	.82	4.04	.36	2.77	1.39
21	4.69	1.16	4.36	---	---	---
22	4.70	2.04	4.88	.44	3.82	1.83

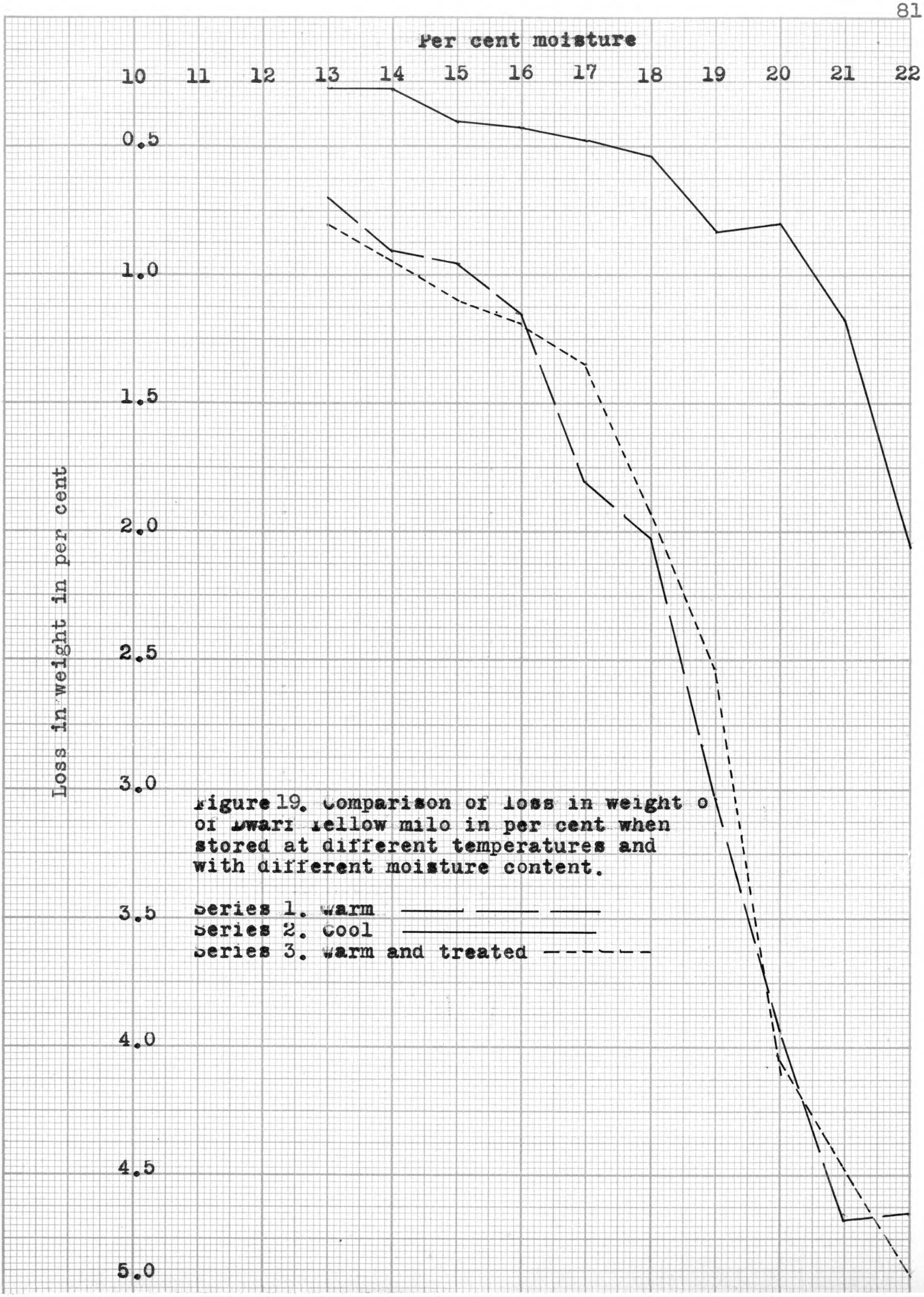


Figure 19. Comparison of loss in weight o of Dwarf Yellow milo in per cent when stored at different temperatures and with different moisture content.

Series 1. Warm ——— ——— ———
Series 2. Cool ————————————
Series 3. Warm and treated - - - - - -

Table XVII. Kafir. Part 1. Summary of loss in weight in per cent at end of second experiment.

Moisture Content Per Cent	Series 1 Warm	Series 2 Cool	Series 3 Warm Treated	Series 4 Warm Sealed	Series 5A Warm Removed 4 Weeks	Series 5B Warm Removed 2 Weeks
10	.22	.11	.22	---	.13	.15
11	.39	.21	.38	---	---	---
12	.51	.35	.49	---	.32	.25
13	.55	.36	.60	---	---	---
14	.73	.59	.70	---	.52	.26
15	.84	.68	.69	---	---	---
16	1.12	.98	1.11	.20	.66	.40
17	1.47	1.02	1.28	----	---	---
18	2.93	1.53	1.63	---	.94	.45
19	3.69	2.77	2.99	---	---	---
20	4.43	3.49	3.72	.43	2.46	.87
21	3.88	3.62	4.51	---	---	---
22	4.73	3.72	4.16	.47	3.23	1.21

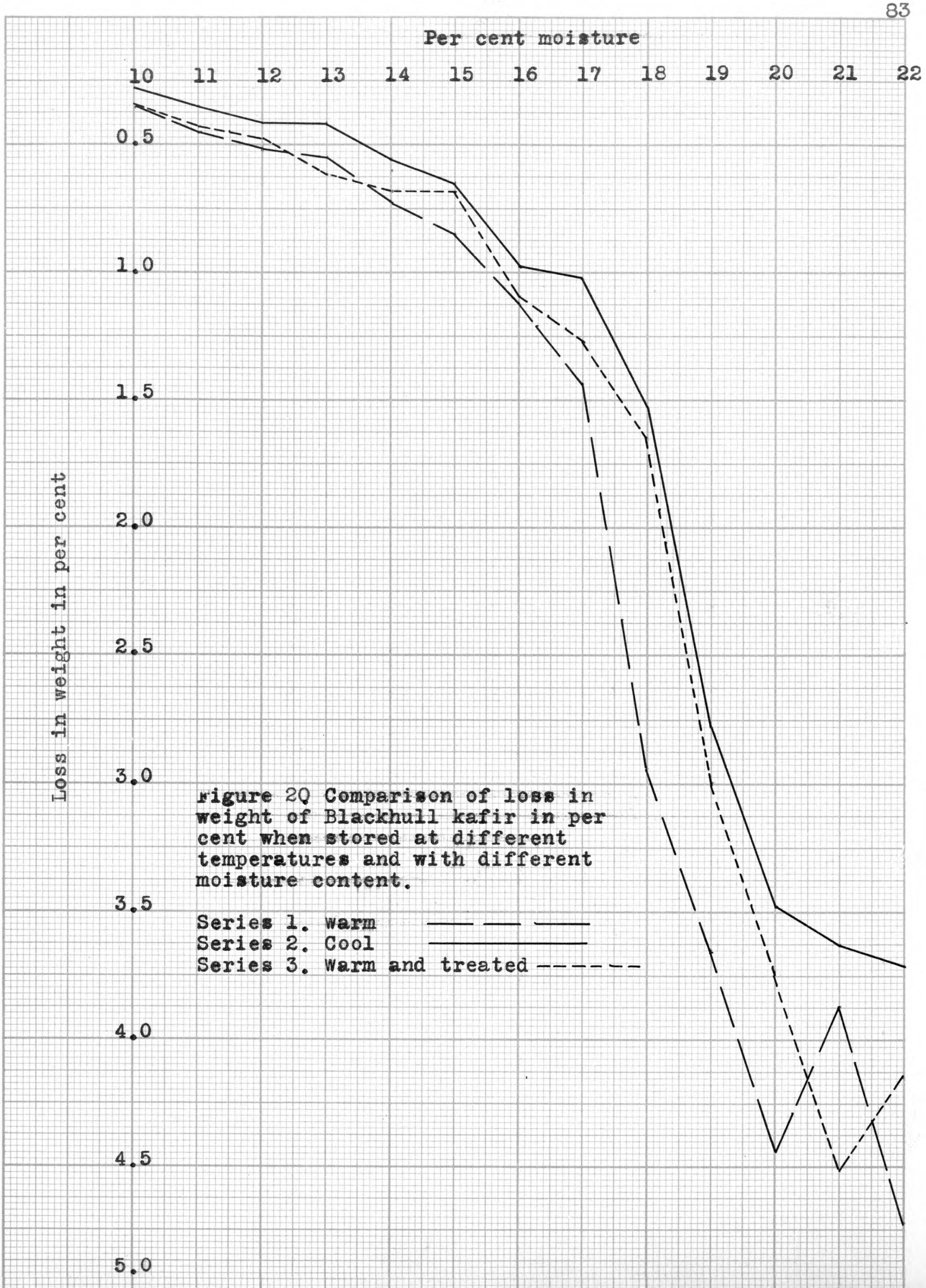


Figure 20 Comparison of loss in weight of Blackhull kafir in per cent when stored at different temperatures and with different moisture content.

Table XVIII. Milo. Part 1. Summary of loss in weight in per cent at end of second experiment.

Moisture Content Per Cent	Series 1 Warm	Series 2 Cool	Series 3 Warm Treated	Series 4 Warm Sealed	Series 5A Warm Removed 4 Weeks	Series 5B Warm Removed 2 Weeks
10	.31	.10	.10	---	.22	.05
11	.42	.22	.44	---	---	---
12	.50	.31	.38	---	.29	.12
13	.53	.41	.67	---	---	---
14	.76	.51	.71	---	.47	.20
15	1.23	.69	.87	---	---	---
16	2.15	1.09	1.14	.17	.82	.53
17	3.51	2.08	2.16	---	---	---
18	4.57	2.98	2.92	---	1.93	.56
19	4.25	4.46	3.65	---	---	---
20	4.86	3.93	4.53	.59	2.94	1.15
21	4.91	4.34	4.48	---	---	---
22	4.29	4.42	4.36	.69	3.61	1.47

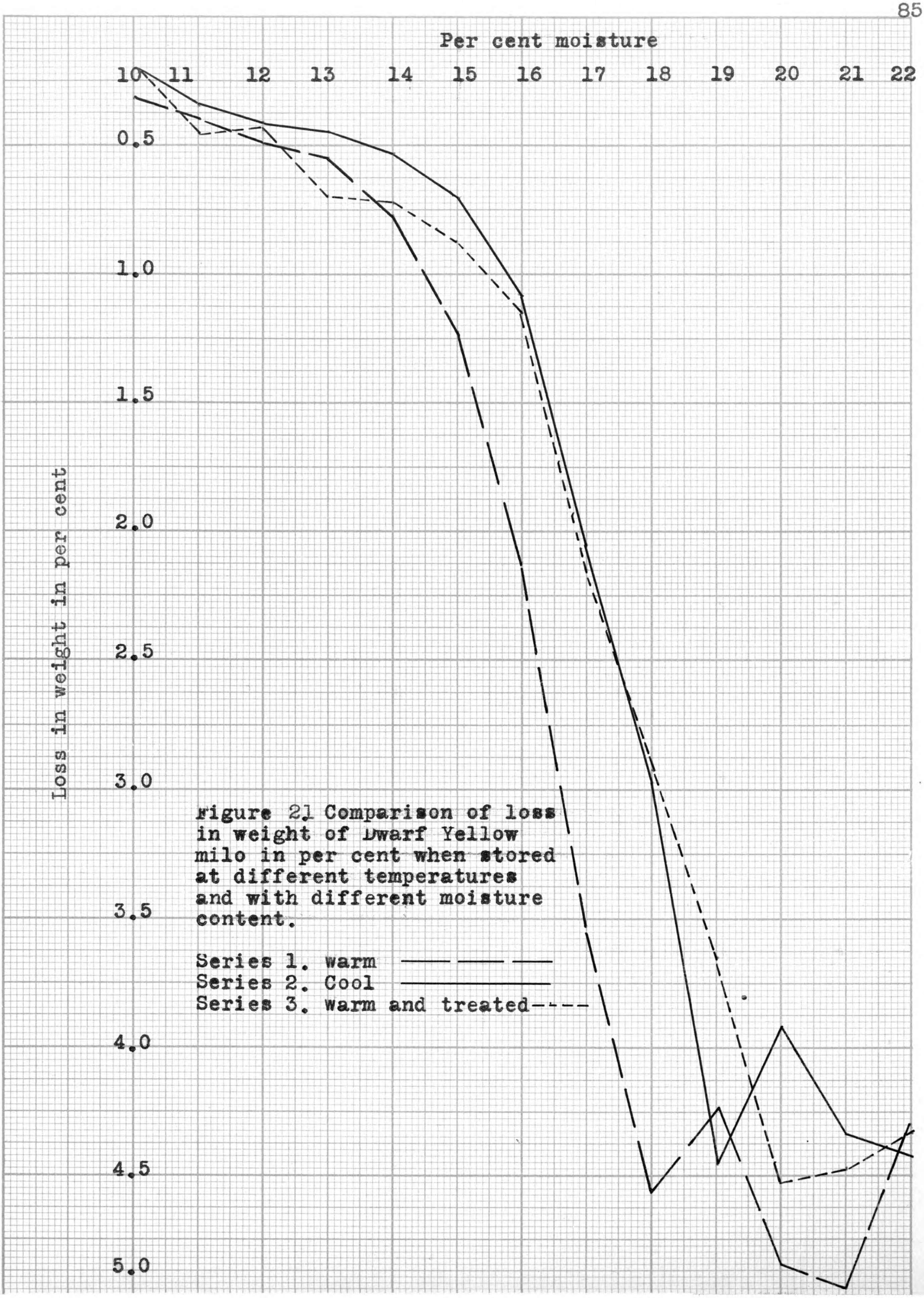


Figure 21 Comparison of loss in weight of Dwarf Yellow milo in per cent when stored at different temperatures and with different moisture content.

Series 1. warm ——— ——— ———
Series 2. Cool ———————————
Series 3. warm and treated----

Volume

A volume study of kafir and milo might well include information relating to the size, shape, and structure of the grain in order to have a better understanding of the adsorption of moisture which is largely responsible for the change in volume of a given amount of grain. By referring to the various Figures presented, it may be observed that there is a constant relation between the amount of moisture in the grain and its volume. In all containers shown in these Figures, there was placed an equal amount of grain, 1000 grams at a given moisture content. After the grain was weighed and placed in the containers, water was added to bring the moisture content of the grain up to the desired percentage. The grain was mixed thoroughly to distribute the water as equally as possible and within 24 hours had increased in volume, in general, in direct relationship to the amount of water added. There may have been some increase in volume after the first 24 hour period, but the largest part of this change in volume due to the added moisture occurred during this short early period.

Ball (13) gives data on a large number of samples of kafir and milo, and gives the weight per 1000 kernels of milo as 36.1 grams, Dwarf milo 31.4 grams, Blackhull kafir

21.6 grams and Dwarf Blackhull 16.6 grams. Coleman et al (18) give the weight per 1000 kernels for milo as 37.8 grams and white kafir 23.9 grams. They also give the volume per 1000 kernels as 28.75 cc. for milo and 18.75 cc. for white kafir. Bidwell (14) and Bidwell et al (15) give the weight of one 1000 kernels of Dwarf Blackhull kafir at 23.5 grams and milo at 33.9 grams. These authors give the average size of grain sorghums as follows:

	Average Thickness mm.	Average Width mm.	Average Length mm.
Kafir	2.46	3.33	3.90
Milo	2.86	4.47	4.42
Feterita	2.76	4.13	4.39

The proportion of different parts of the sorghum grains are shown with a comparison with corn.

	Bran Per Cent	Germ Per Cent	Endosperm		
			Starchy Per Cent	Horny Per Cent	Per Cent
Kafir	6.1	10.0	35.0	48.9	83.9
Milo	5.5	11.1			83.4
Feterita	6.6	7.3			86.1
Corn	7.4	11.5			81.1

Zink (68) gives the specific gravity of yellow milo as 1.22, Blackhull kafir 1.26, Turkey wheat 1.30, Harvest Queen wheat 1.32, Manchu soybeans 1.18, and Wilson soybeans 1.13.

In a study of the structure of the seeds of the various sorghum grains, Swanson and Getty (57) describe the seed coats of feterita, hegari, and kaoliang as revealing upon microscopic examination, a thick starchy layer they call the mesocarp, measuring from 60 to 80 microns in thickness. They place kafir and milo in another group with this layer measuring 35 to 45 microns in thickness. In Red Amber sorgo and broom corn this layer measures only about 10 microns. The thickness of this layer, they say, seems to have some relationship to the water absorbing capacity of the seed, as their tests show feterita absorbed about 45 per cent more water in a two hour period than Red Amber sorgo or Blackhull kafir. The hypodermal and epidermal layers of the pericarp, lying directly above the mesoderm, differed in thickness, texture, and luster, in the different sorghums. Those of feterita were thin and chalky and about 15 microns in thickness, while those of kafir and milo were hard and glossy and approximately 45 microns in thickness.

Although these investigators place kafir and milo in a group containing similar structural characteristics, our results show some difference in time required to germinate. Milo began germination sooner than kafir, yielded to mold attack sooner, and appeared to increase in volume somewhat faster upon the addition of water.

EXPERIMENTAL RESULTS. PART 2

The Influence of Broken Grain on Keeping Quality

The relation of the amount of broken grain in grain sorghums is important. It has been the judgment of nearly every one interested in the keeping qualities of grain sorghums that the percentage of broken grain present greatly influenced the keeping qualities. In order to add to our knowledge on this subject, this part of the experiment was conducted according to the outline as shown in Table 2. Blackhull kafir, of the same lot used in Part 1, was used in the first experiment. That grain contained 16.51 per cent moisture and the tabulations include the results of all samples, but the samples which contained less than 16.51 per cent moisture are used only for checking results of duplicate samples. In the second experiment milo containing 7.59 per cent original moisture was used and all data can be considered in full accordance with the outline of the experiment. It was thought advisable to use milo in one of the experiments as the amount of broken kernels is usually much greater in milo than in kafir.

Moisture

There is no definite correlation between the moisture content of the kafir at the end of the first experiment and the percentage of broken grain present. There is a striking contrast in the final moisture content in both the warm and cool series, as compared with the kafir in Part 1. The moisture content in samples containing 16, 18, and 20 per cent moisture in most cases contained less moisture than at the beginning of the experiment. The samples in Part 1 in this moisture range usually contained more moisture than at the beginning of the experiment. This may have been caused by the greater exclusion of air due to the closer packing of the grain containing broken kernels and consequently less mold growth. However there was no increase in the correlation as the percentage of broken grain increased.

Table XIX. Average moisture content of four samples of kafir in the first experiment containing the same amount of original moisture, for each per cent of broken grain and compared for warm and cool temperatures.

Broken Grain Per Cent	Moisture Content at End of Experiment	
	Warm	Cool
4	13.24	13.54
8	14.45	14.20
12	13.79	12.99
15	13.95	14.69
20	13.52	13.59
25	14.03	14.66

The above table shows that neither broken grain nor temperature difference appeared to form any correlation with the moisture content of these samples. In the second experiment milo was used and the analysis at the end of the experiment showed higher moisture content than in the kafir of the first experiment. There was comparatively little difference in the temperature of the cool and warm series and also little consistent difference in final moisture content. The cool series showed a slightly higher moisture content on the average. The amount of broken grain present and the final moisture content showed no correlation.

Table XX. Kafir. Part 2, Series 1. Summary of moisture content at end of first experiment after being maintained at a warm temperature.

Original Moisture Content Per Cent	Per Cent of Broken Grain					
	4	8	12	15	20	25
	12.51	14.53	14.48	13.63	12.88	13.92
	13.22	14.01	13.70	14.92	13.16	13.32
	13.77	13.76	13.49	14.20	13.87	13.77
16	13.47	15.52	13.51	13.11	14.20	15.21
18	13.29	15.52	15.64	14.94	15.04	15.36
20	21.49	19.75	18.74	19.44	21.52	20.74
22	23.15	21.18	21.19	22.07	22.78	21.83

Table XXI. Kafir. Part 2, Series 2. Summary of moisture content at end of first experiment after being maintained at a cool temperature.

Original Moisture Content Per Cent	Per Cent of Broken Grain					
	4	8	12	15	20	25
	13.25	12.88	12.40	14.66	13.76	14.38
	14.09	14.91	12.97	14.91	13.51	13.80
	13.19	14.50	12.96	15.16	13.06	13.75
16	13.60	14.53	13.63	13.44	14.05	16.71
18	15.35	16.54	14.18	17.06	14.09	15.37
20	17.66	17.57	18.71	19.47	16.79	17.30
22	22.64	21.39	28.37	25.00	23.06	23.39

Table XXII. Milo. Part 2, Series 1. Summary of moisture content at end of second experiment after being maintained at a warm temperature.

Original Moisture Content Per Cent	Per Cent of Broken Grain			
	12	15	20	25
10	8.32	9.80	8.55	10.39
12	10.32	10.49	10.82	12.68
14	11.68	13.81	12.50	15.05
16	16.78	16.91	16.08	17.17
18	19.82	20.28	23.58	22.11
20	24.31	24.51	26.03	25.95
22	24.98	29.21	27.49	29.30

Table XXIII. Milo. Part 2, Series 1. Summary of moisture content at end of second experiment after being maintained at a cool temperature.

Original Moisture Content Per Cent	Per Cent of Broken Grain			
	12	15	20	25
10	8.85	9.24	10.27	8.82
12	10.84	10.84	12.81	10.24
14	12.83	13.80	13.51	13.03
16	16.06	16.04	16.82	17.10
18	22.56	21.27	22.12	23.22
20	28.57	28.79	26.35	24.71
22	28.84	30.94	28.11	28.95

Germination

The records of the first experiment showed no correlation between the percentage germination and the percentage of broken grain. See Tables XXVI and XXVII. However a difference in viability was found in relation to both temperature and moisture as shown in Table XXIV.

Table XXIV. Effect of temperature and moisture on germination of kafir in the first experiment. Average of all percentages of broken grain.

	Average Temperature Degrees C.	Per Cent Moisture 16	18	20	22
		Per Cent Germination			
Cool Series	19.7	65.1	43.1	22.3	0
Warm Series	33.2	32.1	18.1	4.3	0

Table XXV shows the results of the second experiment in which milo was used. The cool temperature so nearly approached the warm temperature during the last half of the time that the influence of temperature was negligible.

Table XXV. Effect of temperature and moisture on germination of milo in the second experiment. Average of all percentages of broken grain.

	Average Temperature Degrees C.	Per Cent Moisture 10	12	14	16	18	20	22
		Per Cent Germination						
Cool Series	27.9	73.2	64.2	10.7	3.2	0	0	0
Warm Series	33.4	78.0	67.5	12.0	1.0	0	0	0

Table XXVI. Kafir. Part 2, Series 1. Summary of average per cent germination of first experiment after being maintained at a warm temperature.

Original Moisture Content Per Cent	Per Cent of Broken Grain 4	8	12	15	20	25
	27	46	27	60	44	27
	29	36	24	30	40	35
	41	50	34	28	25	29
16	28	27	25	48	33	32
18	23	17	19	20	18	12
20	7	6	6	6	1	0
22	0	0	0	0	0	0

Table XXVII. Part 2, Series 2. Summary of average per cent germination of first experiment after being maintained at a cool temperature.

Original Moisture Content Per Cent	Per Cent of Broken Grain					
	4	8	12	15	20	25
	51	56	53	73	63	66
	67	58	67	51	45	78
	64	56	63	74	71	81
16	60	65	56	73	69	68
18	49	38	45	39	38	50
20	33	14	20	24	21	22
22	0	0	0	0	0	0

Table XXVIII. Milo. Part 2, Series 1. Summary of average per cent germination of second experiment after being maintained at a warm temperature.

Original Moisture Content Per Cent	Per Cent of Broken Grain			
	12	15	20	25
10	76	76	80	80
12	72	67	74	57
14	30	6	10	2
16	2	1	0	0
18	0	0	0	0
20	0	0	0	0
22	0	0	0	0

Table XXIX. Milo. Part 2, Series 2. Summary of average per cent germination of second experiment after being maintained at a cool temperature.

Original Moisture Content Per Cent	Per Cent of Broken Grain 12	15	20	25
10	70	70	80	73
12	69	66	69	53
14	14	13	9	7
16	4	0	4	5
18	0	0	0	0
20	0	0	2	1
22	0	0	0	0

Temperature

The effects of temperature are in general the same as in Part 1, and the amount of broken grain present appeared not to be of any particular influence.

Molds

The amount of mold growth present appeared to be less in the presence of broken grains. Respiration of broken grains is greater than that of whole or uninjured grain according to Coleman et al (18), and mold growth usually occurs only on grain which has an injured or broken seed coat (Hurd 30). It would therefore seem that grain with a high percentage of broken kernels would be a decidedly favorable place for heavy mold growth. It appeared however that due to the partial exclusion of air by the close packing of grain containing a high percentage of broken grain, there is a reduction of the supply of free oxygen, which limits or retards the activity of the molds. While this was notably true in general, no consistent differences were observed in mold growth between milo containing 12 per cent broken kernels and milo containing 25 per cent broken kernels, as can be seen by comparing Figure 22 and Figure 23.

Insects

No insects affecting grain were found in the kafir during the first experiment. In the second experiment in which milo was used and summer conditions were present, insects appeared in several samples. Identifications of these insects were made by Prof. George A. Dean, Head of the Department of Entomology, Kansas State College. The insects found were identified as the saw-toothed grain beetle, ~~Oryzaephilus~~ *surinamensis*, L., the square-necked grain beetle, *Silvanus gemellatus*, Duv., and the flat grain beetle, *Cryptolestes pusillus*, Schon.

Almost without exception, the insects appeared in samples containing 14 per cent moisture. This agrees with

Figure 22. Mold growth on milo containing 12 per cent broken grain. Moisture content increases from left to right.

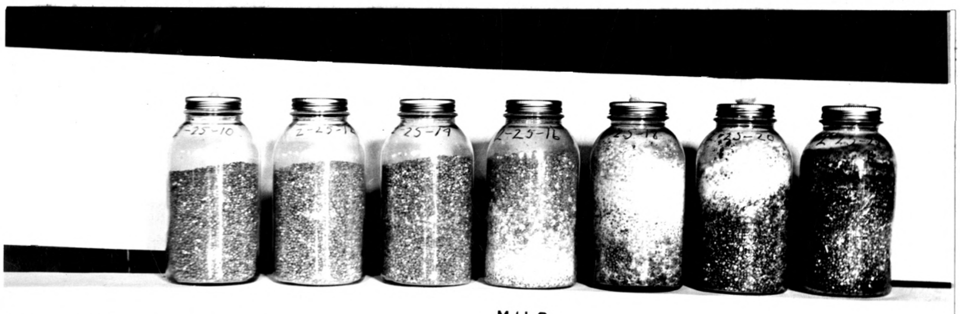


Figure 23. Mold growth on milo containing 25 per cent broken grain. Moisture content increases from left to right.

the conclusions of Lindgren (38) that insects affecting grain become less active in grain containing less than 14 per cent moisture and that they cannot long exist in grain with 10 per cent or less moisture. The milo used in Part 2 of the second experiment was considerably molded at 16 per cent moisture which may account for the absence of infestation in grain of higher moisture content. A number of active insects were transferred to containers of moldy grain and after a few days only one or two live insects could be found, indicating that moldy grain may create a lethal condition for these insects.

Weight per Bushel

Broken kernels affect the weight per bushel of kafir or milo according to the amount present. At the beginning of the first experiment, the weight per bushel was recorded after different percentages of broken grain had been added. These weights and the final weight made from samples containing the same amount of moisture, for the cool and warm series are compared in Table XXX.

Table XXX. Weight per bushel of kafir as affected by different percentages of broken kernels at the beginning of the first experiment, and at the end after storing at warm and cool temperatures.

Broken Grain Per Cent	Average Weight per Bushel: Beginning of Experiment	At End of Experiment: Cool	At End of Experiment: Warm
0	56.2	55.2	54.7
4	55.6	55.2	54.7
8	55.3	54.5	54.3
12	54.7	54.3	53.6
15	54.4	53.5	53.4
20	53.9	53.0	52.9
25	53.0	52.3	51.9

Figure 24 shows graphically the effect of different percentages of broken kernels on weight per bushel. The presence of molds also affected the weight and caused a definite decline in weight per bushel as the amount of mold increased in the samples having the higher moisture contents as shown in Table XXXI. In the second experiment in which milo was used, the original weight was 57.6 pounds per bushel and the reduction in test weight with the addition of broken grain and with added moisture was similar to kafir in the first experiment.

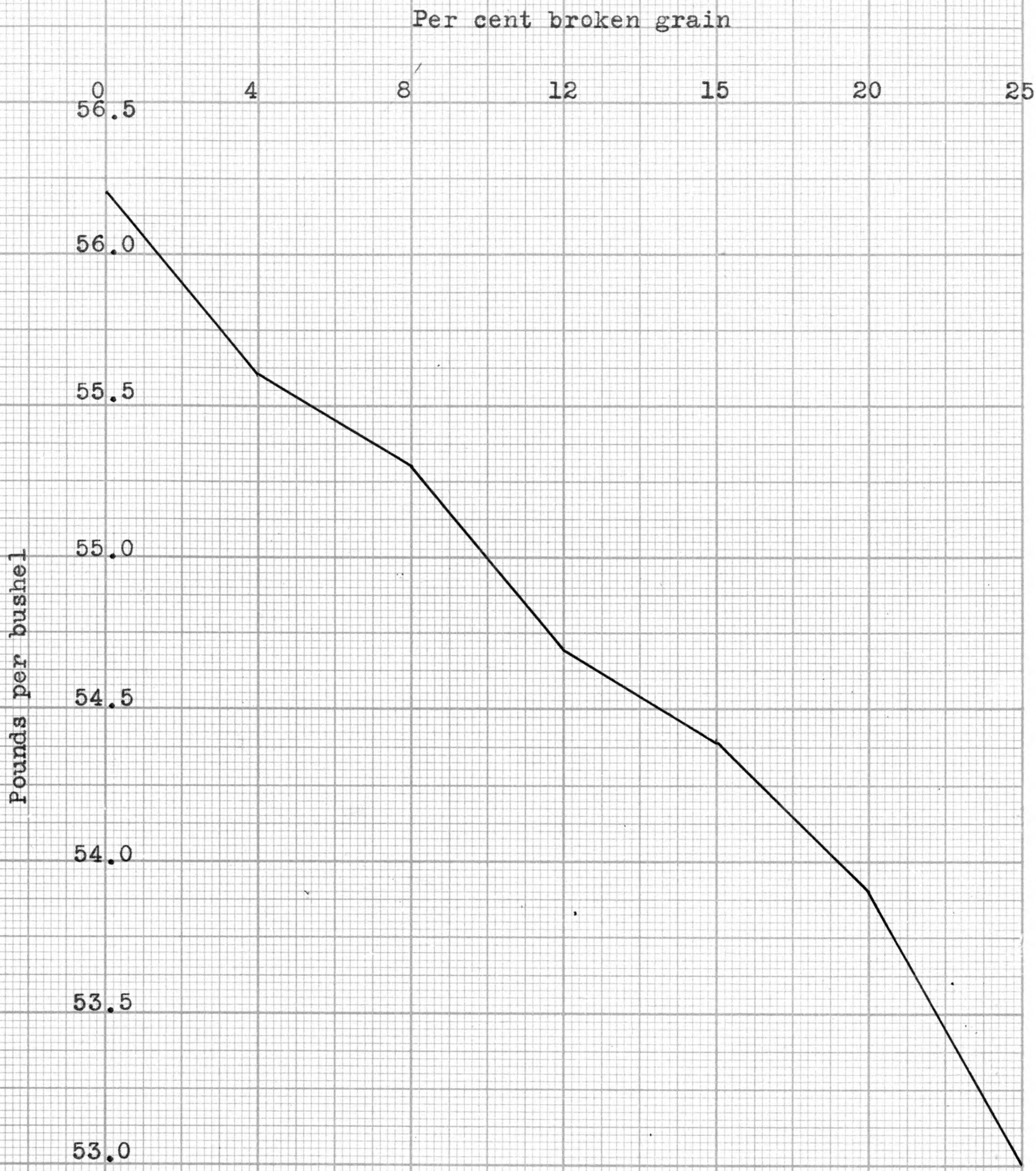


Figure 24 Effect of different percentages of broken grain on weight per bushel of kafir at beginning of first experiment.

Table XXXI. Kafir. Part 2, Series 1. Summary of average weight per bushel at the beginning of the first experiment, and at the end when maintained at a warm temperature.

Original Moisture Content Per Cent	Per Cent of Broken Grain					
	4	8	12	15	20	25
	54.9	54.4	53.7	53.4	53.1	51.9
	54.5	54.4	53.7	53.4	52.7	52.0
	54.8	54.4	53.6	53.3	52.8	51.9
16	54.9	54.3	53.5	53.8	53.0	51.8
18	54.4	53.6	53.1	52.8	52.2	51.0
20	45.1	45.9	47.5	48.6	43.4	44.1
22	44.4	44.4	44.5	43.0	43.7	44.6
Original weight per bushel	55.6	55.3	54.7	54.4	53.9	53.0

Table XXXII. Kafir. Part 2, Series 2. Summary of average weight per bushel at the beginning of the first experiment, and at the end when maintained at a cool temperature.

Original Moisture Content Per Cent	Per Cent of Broken Grain					
	4	8	12	15	20	25
	54.8	54.8	54.3	53.8	52.9	52.6
	55.5	54.6	54.4	53.7	52.6	52.4
	55.4	54.5	54.3	54.0	53.2	51.8
16	55.4	54.4	54.2	53.9	53.3	52.4
18	54.8	54.2	53.9	53.2	52.5	51.6
20	53.4	50.5	51.2	51.3	51.0	50.9
22	47.0	46.1	46.0	46.7	45.7	46.6
Original weight per bushel	55.6	55.3	54.7	54.4	53.9	53.0

Table XXXIII. Milo. Part 2, Series 1. Summary of average weight per bushel at the end of the second experiment when maintained at a warm temperature.

Original Moisture Content Per Cent	Per Cent of Broken Grain 12	15	20	25
10	57.2	57.3	57.3	56.9
12	56.8	56.8	56.2	56.8
14	55.7	49.1	55.0	54.6
16	48.6	43.2	48.5	46.5
18	43.3	46.2	42.0	44.3
20	46.4	45.2	45.4	45.6
22	44.9	45.9	46.1	45.7

Table XXXIV. Milo. Part 2, Series 2. Summary of average weight per bushel at the end of the second experiment when maintained at a cool temperature.

Original Moisture Content Per Cent	Per Cent of Broken Grain 12	15	20	25
10	57.2	57.2	57.1	55.4
12	56.5	56.7	56.4	56.3
14	55.0	55.6	54.4	54.6
16	52.0	48.8	47.3	46.3
18	44.4	43.3	43.5	43.7
20	44.7	43.7	44.3	45.2
22	45.0	46.6	47.1	46.8

Loss in Weight

The samples were weighed each week as in Part 1 of the experiment. Tables XXXV and XXXVI show the loss in weight in per cent for the first experiment. The first four samples contained the same amount of moisture, and they were averaged for each percentage of broken grain. In the series stored at the warm temperature there was the greatest per cent loss in weight in the grain containing the greatest amount of broken grain, while in the cool series the largest percentage loss in weight was in the grain containing the least amount of broken grain and the loss in weight decreased as the percentage of broken grain increased. Therefore no correlation was shown between the percentage of broken grain present and the per cent loss in weight for either temperature. The percentage loss in weight was nearly three times as great in the warm series as in the cool series. The loss in weight increased rapidly with the increase in moisture content.

In the second experiment the loss in weight is shown in Tables XXXVII and XXXVIII. There is little consistent difference in the loss in weight between the warm and the cool series due to the converging temperature levels, but the loss in weight increases consistently in both series with increase in moisture content. In this test all original moisture contents from 10 to 22 per cent were in accordance with the plan for the beginning of the experiment.

Table XXXV. Kafir. Part 2, Series 1. Summary of loss of weight in per cent at end of first experiment after being maintained at a warm temperature.

Original Moisture Content Per Cent	Per Cent of Broken Grain					
	4	8	12	15	20	25
	1.01	.84	.97	.84	1.01	1.14
	1.06	.96	1.03	1.01	.95	1.12
	1.15	.92	.94	.90	1.09	1.16
16	1.21	1.13	.88	.88	1.04	1.21
18	1.30	1.23	1.12	1.37	1.35	1.28
20	3.04	2.97	2.52	1.94	3.66	2.68
22	4.97	4.50	4.47	4.94	4.82	4.29

Table XXXVI. Kafir. Part 2, Series 2. Summary of loss of weight in per cent at end of first experiment after being maintained at a cool temperature.

Original Moisture Content Per Cent	Per Cent of Broken Grain					
	4	8	12	15	20	25
	.44	.44	.33	.33	.33	.32
	.37	.40	.42	.29	.31	.26
	.42	.37	.30	.31	.33	.25
16	.40	.39	.37	.32	.30	.26
18	.47	.44	.37	.55	.45	.38
20	.83	.95	.63	.69	.56	.65
22	.97	1.44	1.75	1.12	1.19	.90

Table XXXVII. Milo. Part 2, Series 1. Summary of loss of weight in per cent at end of second experiment after being maintained at a warm temperature.

Original Moisture Content Per Cent	Per Cent of Broken Grain			
	12	15	20	25
10	.15	.17	.13	.33
12	.41	.45	.45	.35
14	.65	.75	.76	.87
16	1.59	1.91	1.76	2.59
18	4.44	3.89	4.19	4.46
20	4.49	4.01	5.67	4.84
22	5.28	5.16	4.72	4.85

Table XXXVIII. Milo. Part 2, Series 2. Summary of loss of weight in per cent at end of second experiment after being maintained at a cool temperature.

Original Moisture Content Per Cent	Per Cent of Broken Grain 12	15	20	25
10	.01	.20	.27	.29
12	.39	.49	.54	.54
14	.57	.61	.61	.76
16	.97	1.44	1.76	1.90
18	3.28	3.02	3.30	3.79
20	4.46	4.62	4.76	3.69
22	4.42	4.55	4.35	5.08

SUMMARY AND CONCLUSIONS

Moisture and temperature appeared to be the most important factors in grain storage. Kafir and milo may be stored successfully with high moisture content at low temperatures, or with low moisture content at relatively high temperature, but not with both high temperature and high moisture content.

In general, grain sorghums stored at 33.2 degrees C. (91.7 degrees F.) lost moisture when the grain contained below 16 per cent moisture at the start, and gained moisture as the experiment progressed when the grain contained above 16 per cent moisture. The gain in moisture content from the original 22 per cent at the beginning to as high as 33 per cent, was attributed largely to the development and respiration of molds.

Grain sorghums stored at 19.7 degrees C. (67.4 degrees F.) varied much less from the original moisture content as the experiment progressed. There was a gain in moisture only when the original moisture content was 20 per cent or more and this gain was insignificant.

The change in moisture content was small during the first two-week period, but during the second two-week period the change was generally very great, with some additional change in the third two-week period.

The weight per bushel of kafir and milo declined slowly as the moisture content increased from 10 to 15 per cent. There was a rapid decline between 16 and 19 per cent moisture with a slower decline as the moisture content was further increased.

Warm temperatures caused greater decline in weight per bushel than cool temperatures as the moisture content increased.

Grain stored under anaerobic conditions declined less in weight per bushel than when stored under aerobic conditions.

In most instances the decline in weight per bushel occurred largely during the first two weeks.

It was difficult to obtain uniform samples and therefore uniformity in test weight per bushel of grain containing high moisture content and in which a badly molded condition existed.

The loss in weight during the first experiment was approximately one-third as much when stored at 19.7 degrees C. (67.4 degrees F.) as when stored at 33.2 degrees C. (91.7 degrees F.)

The loss in weight increased slowly when the grain contained 10 to 15 per cent moisture and increased rapidly as the moisture increased above 15 per cent.

Mold spores were naturally present on kafir and milo used in these tests.

Milo was more susceptible than kafir to the attacks of molds which affect grain.

Under more favorable conditions of moisture and temperature mold growth started in a few days and the maximum development usually occurred during the second week.

Mold growth occurred on kafir and milo with a moisture content as low as 11 or 12 per cent, but usually began at 13 to 14 per cent moisture. The point at which grain sorghums begin to deteriorate coincides closely with the point at which molds begin to develop.

In these experiments the predominating molds were identified as *Aspergillus niger*, *A. flavus*, and *Cephalothecum roseum* Cda. This last named mold is pink and occurred largely on grain stored at cool temperatures.

Mold growth in the high moisture samples increased respiratory activity sufficient to increase the moisture content from eight to ten per cent in many of the samples.

Treatment with Ceresan or Semesan as used in these experiments retarded but did not prevent mold growth on kafir and milo. After molds once began to grow on treated grain they seemed to spread more uniformly throughout the mass of grain than in the untreated series.

Milo appeared to begin germination sooner than kafir under like conditions.

There was a consistently higher per cent of germination of both kafir and milo after storage under cool conditions. Kafir in the cool series of the first experiment germinated unusually high in the higher moisture contents. The per cent of germination declined in the higher moisture ranges approximately in proportion to the amount of mold growth present.

The per cent of germination in the sealed series declined in approximate accord with the apparent amount of alcoholic fermentation.

The volume of kafir and milo increased, in general, in approximate relationship to the moisture content of the grain. When water was added the change in volume occurred largely in the first twenty-four hours, with milo increasing in volume slightly faster than kafir.

The amount of broken grain present had an appreciable effect on germination.

The amount of mold growth was in inverse proportion to the amount of broken grain except when only small amounts were present. It appears that the more broken grain present, the closer the grain will pack and more air is excluded from the central portion of the mass and that there is less mold growth.

The insects appearing in the milo in the second experiment were the saw-toothed grain beetle, the square-necked grain beetle, and the flat grain beetle. They appeared almost entirely in milo containing 14 per cent moisture.

There was a definite correlation between the percentage of broken grain present and the weight per bushel. There was also a consistently higher weight per bushel of kafir kept at a cool temperature than when stored at a warm temperature, although the difference was not great.

The critical point in the moisture range in kafir and milo, as shown in Figures 25 to 28 inclusive, appeared generally to be between 13 and 15 per cent. It appears that kafir will carry slightly more moisture than milo and keep safely. Storage difficulties may occur at 13 per cent and less moisture and under certain circumstances with cool temperature these grains containing more than 15 per cent moisture may be safely stored.

Tabular summations of the condition of the grain at the end of the treatment in the several experiments are given in Tables XXXIX to XLII inclusive.

Table XXXIX. Kafir. Part 1. Summary of condition of grain at end of first experiment.

Moisture Content Per Cent	Series 1 Warm	Series 2 Cool	Series 3 Warm Treated	Series 4 Warm Sealed	Series 5A Warm Removed 4 Weeks	Series 5B Warm Removed 2 Weeks
10	Good	Good	Good		Good	Good
11	Good	Good	Good			
12	Slightly musty	Good	Good	Good	Good	Good
13	Musty	Good	Good			
14	Very musty	Good	Good		Slightly musty	
15	"	Good	Good			
16	"	Good	Good	Good	Very musty	Good
17	"	Slightly musty	Good			
18	Very moldy	Very musty	Foggy with black spores		Moldy	Musty
19	"	Moldy	Moldy black fog			
20	Very moldy caked	Moldy	Moldy black fog	Odor fermentation	Very moldy	Moldy
21	Very moldy caked solid	Very moldy	"			
22	"	"	"	Strong odor fermentation	Very moldy	Moldy

Table XL. Milo. Part 1. Summary of condition of grain at end of first experiment.

Moisture Content Per Cent	Series 1 Warm	Series 2 Cool	Series 3 Warm Treated	Series 4 Warm Sealed	Series 5A Warm Removed 4 Weeks	Series 5B Warm Removed 2 Weeks
10	Good	Good	Good		Good	Good
11	Good	Good	Good			
12	Good	Good	Good	Good	Good	Good
13	Good	Good	Good			
14	Good	Good	Good		Good	Good
15	Stale odor	Good	Good			
16	Musty	Stale odor	Stale odor	Good	Musty	Good
17	Very musty	Musty	Musty			
18	"	Very musty	Foggy-black Mold spores		Moldy	Musty
19	"	"	"			
20	Badly molded caked	Moldy	Foggy-black and brown mold spores	Odor fermentation	Very moldy	Moldy
21	"	Very moldy not caked	Very moldy			
22	"	"	Very moldy caked	Strong odor fermentation	Very moldy	Moldy

Table XLI. Kafir. Part 1. Summary of condition of grain at end of second experiment.

Moisture Content Per Cent	Series 1 Warm	Series 2 Cool	Series 3 Warm Treated	Series 4 Warm Sealed	Series 5A Warm Removed 4 Weeks	Series 5B Warm Removed 2 Weeks
10	Good	Good	Good		Good	Good
11	Good	Good	Good			
12	Good	Good	Good	Good	Good	Good
13	Good	Good	Good			
14	Stale	Good	Good		Trace musty	Good
15	Slightly musty	Slightly musty	Stale			
16	Moldy throughout	Musty	Musty	Moldy	Musty	Musty
17	Badly molded	Badly molded	Moldy throughout			
18	"	"	"		Moldy throughout	Moldy
19	"	"	"			
20	"	"	"	Odor fermentation	Very moldy	Moldy
21	"	"	"			
22	"	"	"	Strong odor fermentation	Very moldy	Moldy

Table XLII. Milo. Part 1. Summary of condition of grain at end of second experiment.

Moisture Content Per Cent	Series 1 Warm	Series 2 Cool	Series 3 Warm Treated	Series 4 Warm Sealed	Series 5A Warm Removed 4 Weeks	Series 5B Warm Removed 2 Weeks
10	Good	Good	Good		Good	Good
11	Good	Good	Stale odor			
12	Stale odor	Good	Trace musty odor	Good	Slightly musty	Good
13	Trace musty odor	Trace musty odor	Slightly musty			
14	Musty	Musty	Musty		Musty	Good
15	Moldy	Moldy	Musty			
16	"	"	Moldy	Good	Moldy	Musty
17	"	"	"			
18	"	"	"		Very moldy	Moldy
19	"	"	"			
20	"	"	"	Odor of fermentation	Very moldy caked	
21	"	"	"			
22	"	"	"	Strong odor fermentation	Very moldy caked	Moldy

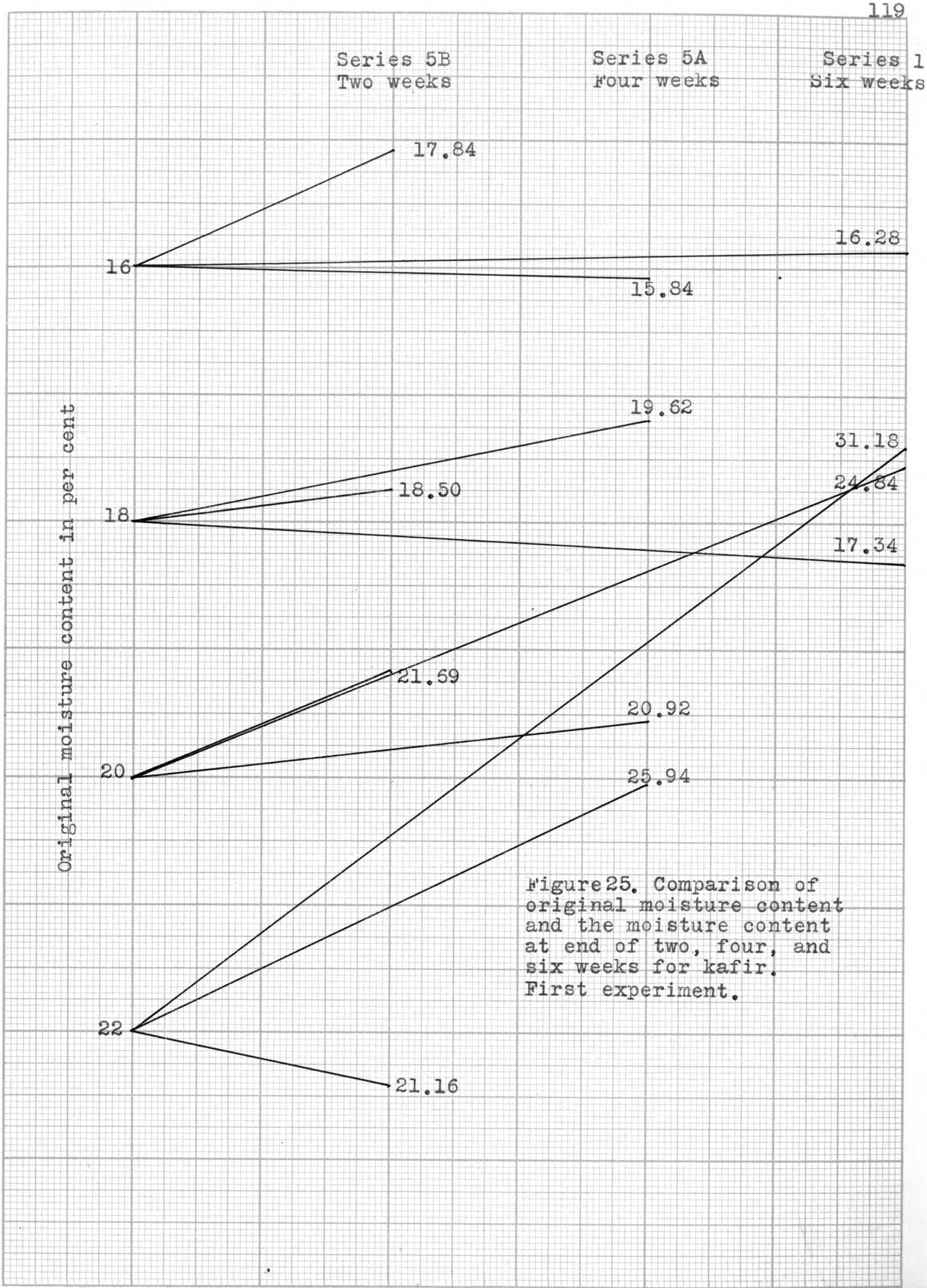


Figure 25. Comparison of original moisture content and the moisture content at end of two, four, and six weeks for kafir. First experiment.

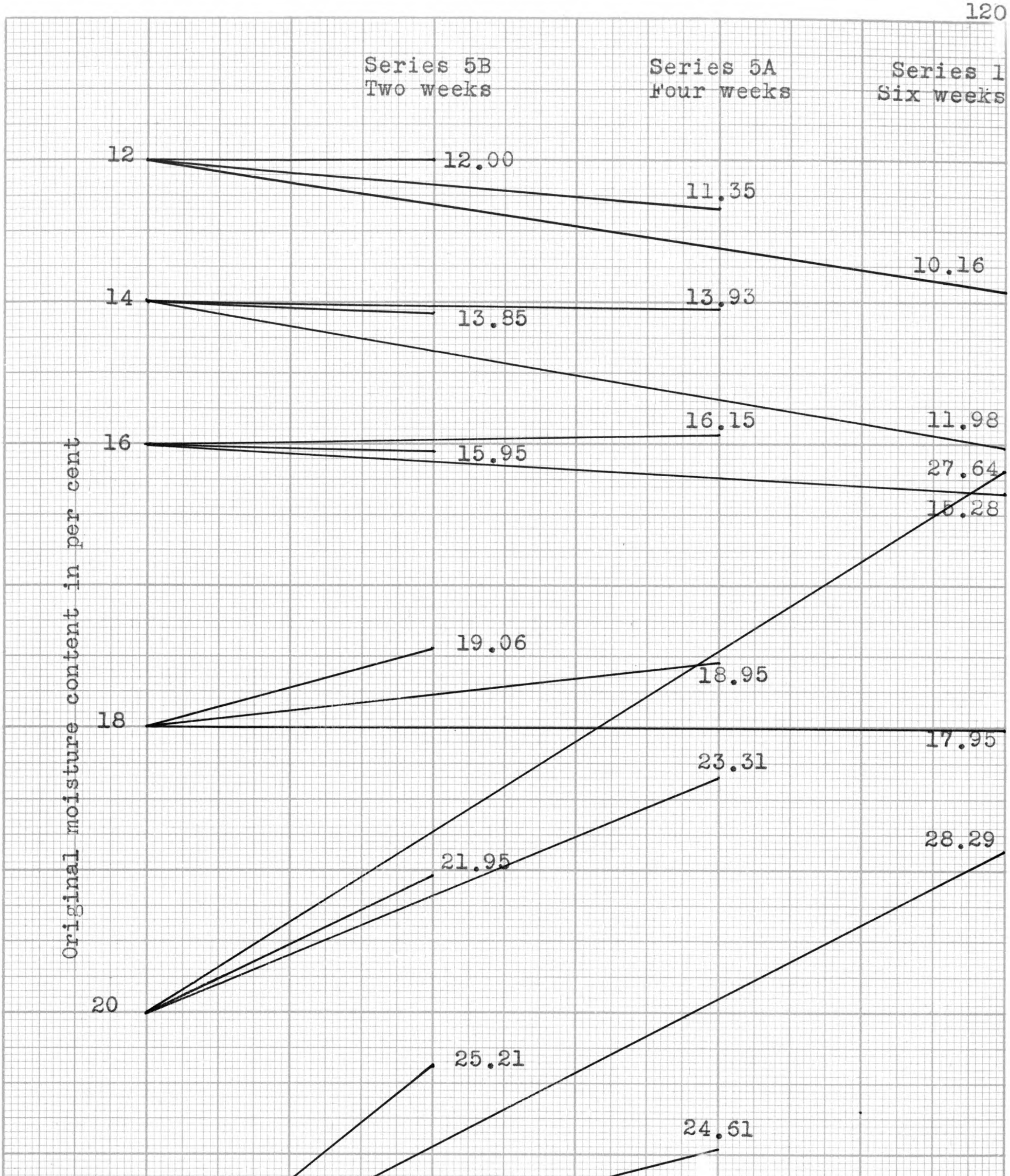


Figure 26 Comparison of original moisture content and moisture content at end of two, four, and six weeks for milo. First experiment.

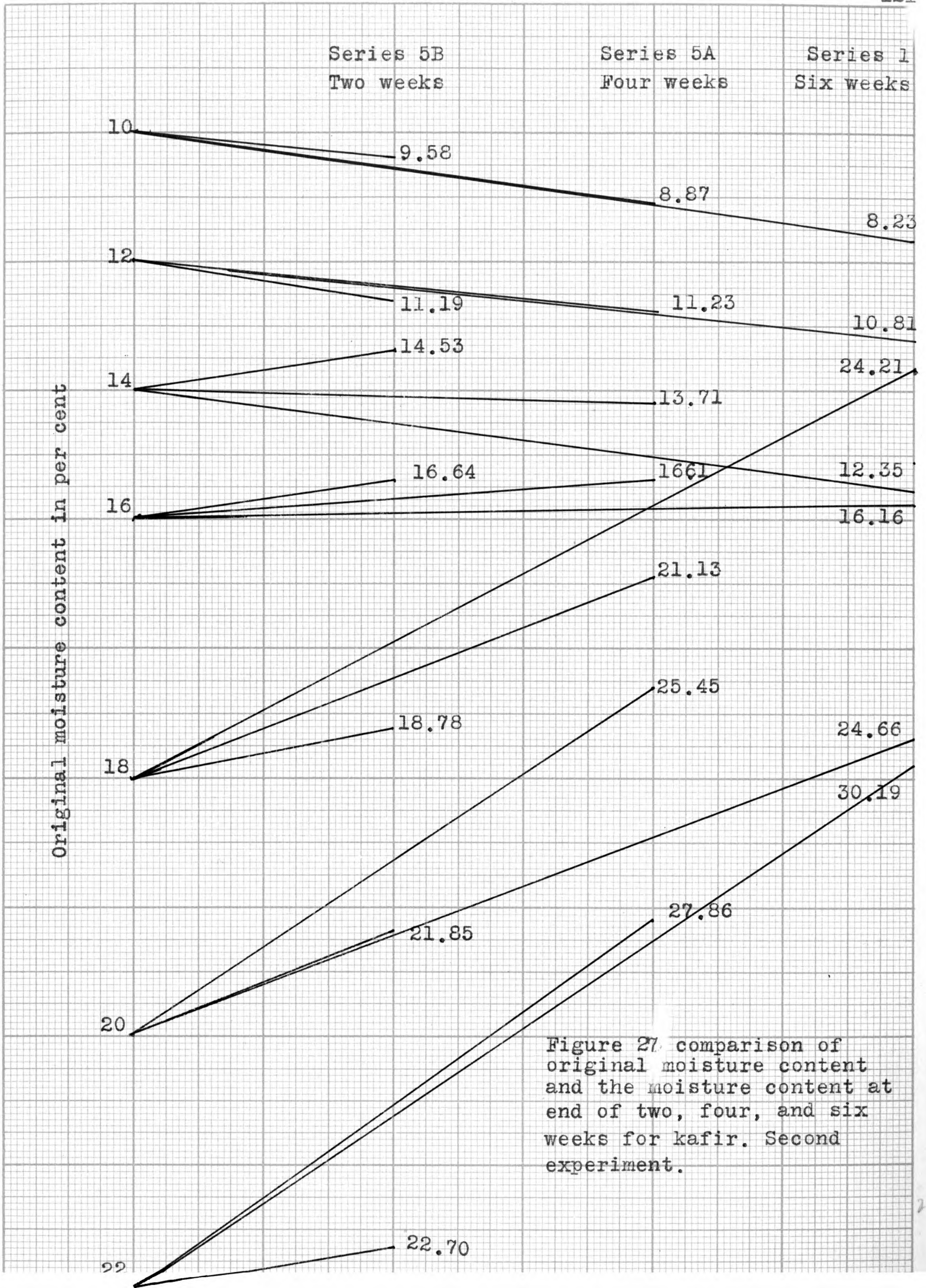


Figure 27 comparison of original moisture content and the moisture content at end of two, four, and six weeks for kafir. Second experiment.

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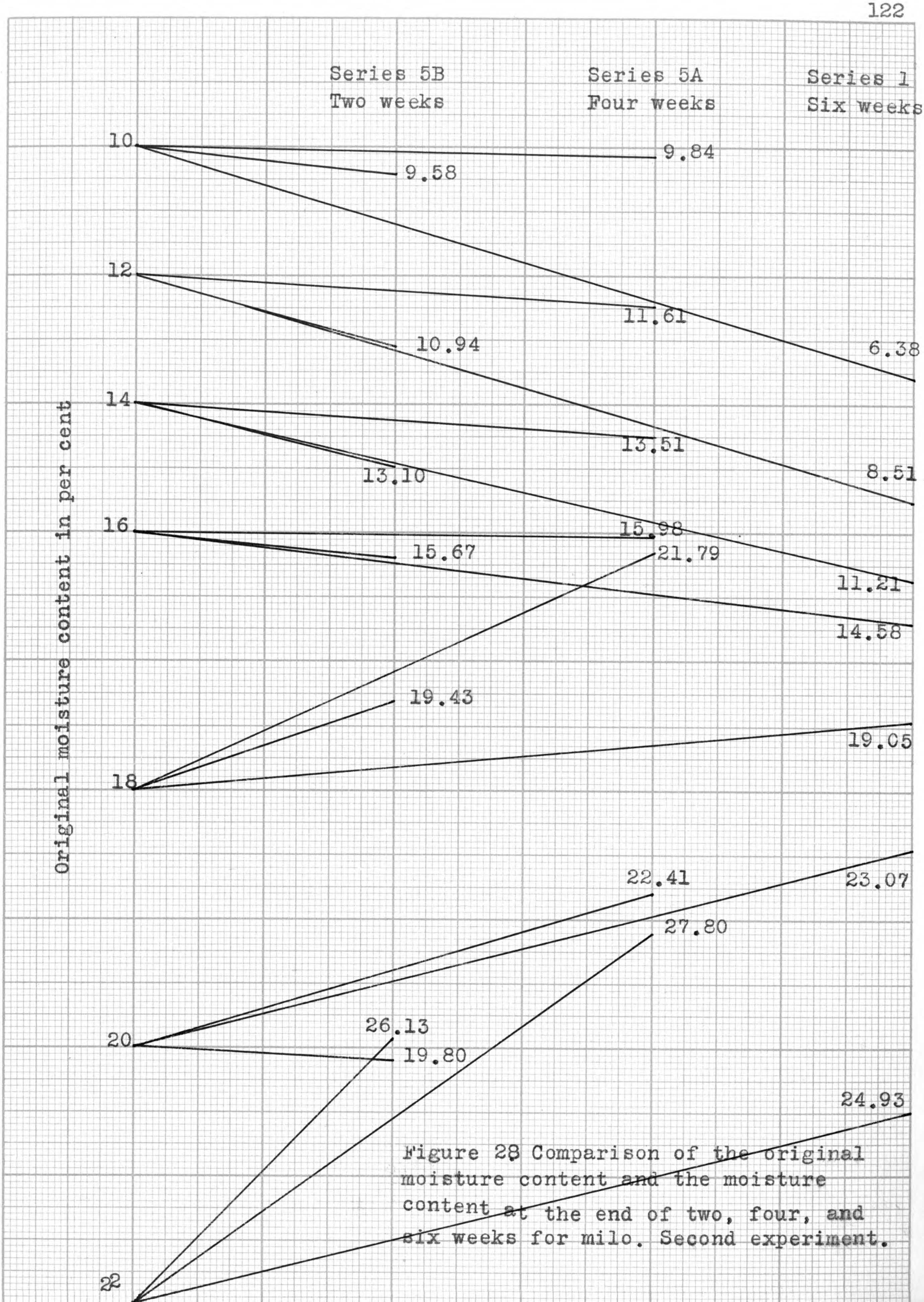

Figure 28 Comparison of the original moisture content and the moisture content at the end of two, four, and six weeks for milo. Second experiment.

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