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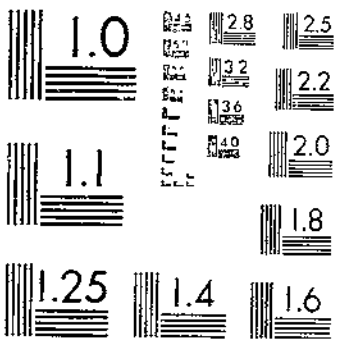

MICROCOPY RESOLUTION TEST CHART
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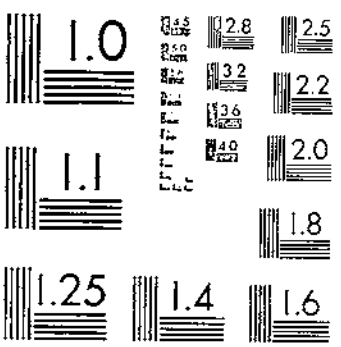

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INFLUENCE OF STORAGE TEMPERATURE AND HUMIDITY ON KEEPING QUALITIES OF ONIONS AND ONION SETS

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INTRODUCTION

The purpose of the investigations described and discussed herein was to study the physiological and pathological reactions of onions and onion sets stored under different controlled temperature and humidity conditions.

Onions represent one of the most important vegetable crops that are stored extensively during the fall and winter seasons. Although onions are grown in many of the Southern States the varieties produced are not usually suitable for storage purposes, and they are therefore marketed for consumption immediately after harvest. On the other hand, the late varieties grown in the North and maturing in September and October may be stored successfully for considerable periods of time. The principal districts in the North where onions are grown and stored in commercial quantities include the muck deposits of New York, Michigan, Ohio, Indiana, and Minnesota. In many other Northern States they are produced and stored on a smaller scale for home or local supply.

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USUAL METHODS OF ONION STORAGE

The bulk of the onions grown in the States mentioned includes the varieties classified within the globe-type group, which constitute the so-called "good keepers." Outside of this belt, States in which onions are stored in large commercial quantities are Colorado, Idaho, and Oregon. The onions that are stored in these Western States are principally of the Spanish type, usually known as Valencias.

Perhaps three-fourths of the commercial-storage onions are held in common storage in the particular sections in which they are grown. "Common storage" refers to the storage of products in suitably insulated buildings in which the temperature is largely governed by weather conditions but where extremes of temperature can usually be modified by manipulation of the ventilating system. By judicious management of the common-storage house, the winter supply of northern-grown onions usually can be kept in good condition until about the first of March. For satisfactory holding after this date onions usually must be placed in cold storage. In general about one-fourth of the crop of storage onions is put directly into commercial cold storage where the temperature is mechanically maintained at about 32° F. These onions are customarily sorted and graded after being cured, and are then put into sacks in which they are subsequently marketed.

As is well known, success in holding onions in storage depends on employing late-maturing varieties harvested when sufficiently mature; on careful handling during harvesting, curing, and storing; and on having the onions thoroughly cured when stored. The principal object in having these onions mature late is that they may not be ready for storage before October or early November, when the night temperatures are low enough to keep the storage houses cool.

When onions are to be put in common storage they usually are cured in the field in slat crates holding about a bushel, in which they are stacked in tiers and covered to shed the rain. They are then topped, if this has not already been done before curing, and sorted to remove all thick or bottle-necked specimens, and those known as splits or doubles, which keep poorly. The sorted onions are then usually put back into the field crates, and these are stacked in the storage room. One-inch-thick strips should be placed over each layer of crates in order to separate them and to hold the tiers apart sufficiently to permit air circulation over and under each crate, while a space of about 1 foot should be left clear next to the walls of the building for the same purpose. When removed for marketing the onions are again sorted, graded, and sacked for shipment.

The storage-house walls and roof should be insulated sufficiently to protect the onions from freezing. During severe winter weather some heat may be necessary. Usually concrete floors are preferred, since less moisture from the soil will get into the storage atmosphere. In addition to ventilators in the roof, inlet ventilators in the walls near the floor and windows near the eaves are also most desirable to insure the maximum amount of air change. In this way it is possible to take advantage of the cool night air during the fall or in mild winter weather and to maintain the inside air as dry as possible by ventilation during dry weather, when the outside-air temperature is not low enough to freeze the onions.

Onion sets are cured and held in common storage in practically the same manner as large onions, except that they are handled in shallow slat-bottom crates about 3 feet square and 4 inches deep, with corner posts extending about 4 inches above the sides so that air can circulate between the crates when they are stacked. Sometimes sets are treated further, after the usual curing and before going into storage, by passing through them a stream of air heated to 80° or 90° F. for a period of 5 to 6 hours. By thoroughly drying the necks this treatment is reported to reduce considerably the amount of neck rot. When ready for shipment the sets are cleaned again by passing them through a strong draft of air before they are sacked.

PREVIOUS INVESTIGATIONS

Practical methods for the handling and storing of onions have been well described by various writers (*1*, *4*).[2] The usual storage temperature recommended is about 32° F., or slightly above the freezing point, with a low relative humidity. The average freezing point of cured onions is given by Wright and Taylor (*8*) as 30.09°. While this is the temperature at which freezing of the tissue is likely to occur, it is common opinion that slight freezing does not injure onions provided they are thawed out slowly and kept dry. One writer (*7*) reports that onions carried for 6 months at 25° and then carefully thawed were entirely satisfactory and marketable. A storage temperature of 32° is usually considered best for onion sets, since the development of decay is less rapid than at higher temperatures and also because it is thought that the subsequent production of seed stalks is minimized. This view is supported by the work of Boswell (*2*) and Jones (*3*), who found that mother bulbs stored at the lower temperatures tend to produce fewer seed stalks than those stored at higher temperatures. The work of Boswell clearly showed further that a storage temperature of 32° prevented practically all sprouting, whereas at 40° and at 50° increasing numbers of sprouting onions were found.

Probably the most serious storage disease of onions is the one commonly known as *Botrytis* neck rot. Three types of this disease produced by three species of *Botrytis* (*B. allii* Munn, *B. byssoidea* Walker, and *B. squamosa* Walker) are described by Walker (*6*). These fungi usually enter through the neck or through mechanical wounds when the bulbs are not well dried. The importance of thorough curing or drying and the careful sorting out of all wounded bulbs and all thick-necked specimens that are difficult to dry cannot be overemphasized as prerequisites to successful storage. Walker (*5*) has demonstrated that neck rot can be controlled by artificial curing or drying.

FACTORS INVOLVED IN SUCCESSFUL STORAGE

Some of the factors affecting the successful storage of onions, as recognized by well-informed growers, are soil, cultural methods, weather, degree of maturity, method of handling, and storage temperature and humidity. Onions grown in certain general localities keep consistently better than those grown in other localities, doubtless owing to soil and climatic adaptability and accounting in large

[2] Italic numbers in parentheses refer to Literature Cited, p. 37.

measure for the segregation of onion-producing areas. The widely different soil types of individual farms may also greatly influence the keeping qualities of the onions produced. Satisfactory development in the field is influenced by the weather, by the prevalence of disease or insect pests, and, of course, by the care given by the grower. Suitable weather is as important during the curing period as during the growing season. When dug, onions should not be immature or overmature. After harvest, onions should be handled with as few operations as possible to avoid injury and the consequent spread of diseases in storage.

MATERIAL AND METHODS

The experimental work described in this bulletin was carried on at the storage laboratory at Arlington Experiment Farm, near Washington, D. C., during the period 1925–31.

During these investigations the varieties of onions studied were all grown in commercial onion-producing sections of this country and in most instances were procured on the local Washington market. Purchases were made early enough in the season to insure the onions had not previously been in storage and yet late enough to obtain in most instances well-matured stock that was suitable for storage from a commercial standpoint. Care was always taken to obtain lots that had just arrived, to eliminate as much as possible the effects of various conditions on the market.

Unless otherwise stated all results given herein are based on actual counts rather than on weight.

VARIETIES STUDIED

The varieties studied include the Ohio Yellow Globe, Southport White Globe, Valencia or Denia, Bermuda, and three varieties of sets, namely, Yellow Strasburg, White Portugal, and Red Wethersfield. These varieties will be discussed in the order given.

STORAGE CONDITIONS

The desired temperature and humidity conditions were obtained by storing the onions in nine galvanized-iron chambers approximately 3 feet 6 inches in length, 2 feet 11 inches in width, and 3 feet 4 inches in height. Three of each of these chambers were installed in storage rooms maintained constantly at temperatures of 32°, 40°, and 50° F. Because of the free conductivity of the thin metal walls, the temperature of each group of chambers closely approximated that of the storage room in which the chambers were located. Desired humidities were manually controlled by exposing different quantities of calcium chloride or water in large shallow pans under slatted false floors in each chamber. Air circulation was supplied in each group of chambers by small fans driven from a line shaft operated by a motor. In the door of each chamber was a small glass window through which wet- and dry-bulb thermometers, directly in line with the draft from the fan, could be read. Distilled water was supplied to the wet bulb by a cotton wick extending from a small bottle supported just below the thermometer.

During the seasons of 1925–26 and 1926–27, low, medium, and high relative humidities in each group of chambers at each storage temperature were arbitrarily maintained at approximately 65, 80, and

90 percent. At the beginning of the 1927–28 season it was decided to adjust the relative humidities in the respective groups of chambers so that there would exist a comparable relative evaporating efficiency in the corresponding low, medium, and high humidities at each of the temperatures used. With the lowest humidity readily obtained at 32° F. as a basis, the other humidities were determined by calculation and were maintained as nearly constant as possible by the method of control already described. The calculated humidities, with comparable saturation deficits, are given in table 1. This arrangement of humidities was followed during the rest of the investigation.

TABLE 1.—*Calculated humidities, with corresponding saturation deficits at 32°, 40°, and 50° F., to be maintained as nearly as possible in the storage chambers*

Storage temperature (°F.)	Low relative humidity	Saturation deficit (vapor pressure) in mercury	Medium relative humidity	Saturation deficit (vapor pressure) in mercury	High relative humidity	Saturation deficit (vapor pressure) in mercury
	Percent	*Inch*	*Percent*	*Inch*	*Percent*	*Inch*
32	84.0		78.0		89.0	
40	72.9	0.067	85.0	0.037	93.5	0.016
50	81.0		89.0		98.0	

YELLOW GLOBE

SEASON OF 1925–26

Two lots of New York-grown stock were studied during the season of 1925–26. The onions of lot 1 were selected and purchased from a drying shed in the field and, being well-matured and dry, they were bagged and expressed direct to the laboratory at Arlington Experiment Farm. They arrived on November 1 and because of delay in the preparation of certain equipment they were put temporarily in storage at 40° F. with a relative humidity of 80 percent. On November 11 the onions were removed to the workroom, where all sprouted, decayed, misshapen, and injured specimens were discarded. After the contents of all the bags had been thoroughly mixed together to obtain uniformity, nine 1-bushel slat crates were filled and 1 was stored in each of the special chambers.

Lot 2 was purchased on November 11 on the Washington market. This lot was taken directly from a car that had just arrived from central New York, and although only of fair size the onions were selected because they were rather damp and not well cured. To dry off the surface moisture the onions were emptied into slat bushel crates and stacked in an airy location in the workroom, where the windows and doors remained open during the daytime. On November 18 the onions were sorted and mixed in the same manner as lot 1 and stored in the same chambers in slat crates.

Both lots were inspected on January 7 and February 16 to determine the actual numbers of specimens remaining dormant and those showing sprouts or top growth, roots, and decay. All specimens showing both sprouts and roots were classed as sprouted. In this connection it is desired to point out that among dealers, sprouted onions are discounted more than rooted onions, since sprouted onions are usually soft and not usable, whereas rooted onions are usually

relatively firm and the roots readily rub off in handling. After each inspection only the sound dormant specimens were returned to the storage chambers. The results of the inspections, as shown in table 2, are expressed in percentages and are cumulative or progressive; that is, the results of each inspection are combined with those of the preceding one.

TABLE 2.—*Conditions found in Yellow Globe onions (seasons of 1925–26 and 1926–27) after storage for various periods at 32°, 40°, and 50° F., with low (65 percent), medium (80 percent), and high (90 percent) relative humidities at each temperature*

Year and lot no.	Storage period	Relative humidity	Condition after storage at indicated temperature											
			32° F.				40° F.				50° F.			
			Dormant	Sprouted	Rooted	Decayed	Dormant	Sprouted	Rooted	Decayed	Dormant	Sprouted	Rooted	Decayed
1925–26	*Days*		*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
1	57	Low	99.2	0.0	0.4	0.4	92.1	4.8	0.9	2.2	94.0	3.7	1.4	0.9
		Medium	96.4	.4	0	3.2	92.9	3.9	.8	2.4	93.2	2.0	2.0	2.8
		High	93.1	2.1	2.2	2.6	89.2	3.3	3.8	3.7	82.2	6.9	4.4	6.5
	97	Low	97.7	0	.4	1.9	83.3	10.5	.9	5.3	86.6	9.2	1.4	2.8
		Medium	94.6	.4	0	5.0	85.8	7.4	3.2	3.6	86.0	8.0	2.0	0.0
		High	85.3	2.8	7.8	4.1	49.2	9.6	36.8	4.4	45.9	16.7	18.9	18.5
2	59	Low	79.7	.3	9.4	10.6	68.4	4.9	16.6	10.1	42.9	8.6	25.5	23.0
		Medium	79.3	.5	4.3	15.9	66.1	2.1	29.2	2.6	55.4	5.1	26.6	12.9
		High	45.4	2.4	36.6	15.6	32.4	7.5	49.5	10.6	35.2	3.5	49.3	12.0
	90	Low	71.4	.6	11.7	16.3	50.7	8.1	25.9	15.3	26.9	15.6	30.0	27.5
		Medium	65.1	.5	13.7	20.7	43.0	4.7	39.2	13.1	41.0	10.7	27.9	20.4
		High	17.0	2.4	56.3	24.3	8.4	8.9	69.0	13.7	13.7	5.2	63.5	17.6
1926–27														
3	32	Low	100.0	0	0	0	99.6	0	0	.4	100.0	0	0	0
		Medium	100.0	0	0	0	99.2	0	.8	0	98.9	.7	.4	0
		High	97.0	0	2.6	.4	78.3	.4	21.3	0	91.0	.7	8.0	.3
	94	Low	100.0	0	0	0	98.7	.4	0	.9	99.3	.7	0	0
		Medium	100.0	0	0	0	98.0	.8	3.2	0	97.4	1.1	1.1	.4
		High	95.3	0	3.5	1.2	77.1	.4	22.1	.4	56.7	2.4	40.0	.3
4	32	Low	98.2	0	0	1.8	99.2	.4	0	.4	95.3	1.4	0	3.3
		Medium	97.5	.4	0	2.1	96.5	2.2	.4	.9	94.6	1.8	.9	2.7
		High	97.6	1.4	.5	.5	86.9	2.4	5.7	5.0	87.2	0	10.0	2.8
	94	Low	82.9	.5	.5	16.1	86.1	.9	0	13.0	79.9	3.7	0	16.4
		Medium	83.1	.9	0	16.0	82.4	3.2	.4	14.0	73.5	2.4	2.4	21.7
		High	88.3	1.4	.5	9.8	69.0	5.0	6.0	19.1	53.2	3.6	22.5	15.7
5	57	Low	97.6	0	0	2.4	95.2	2.4	0	2.4	94.4	4.8	0	.8
		Medium	94.7	.9	0	4.4	84.8	5.6	4.8	4.8	54.8	15.6	17.8	11.8
		High	90.5	.0	1.6	7.9	75.0	8.1	15.3	1.6	52.2	0	38.9	8.9
	117	Low	93.0	1.7	0	5.3	58.3	10.4	27.0	4.3	66.1	32.2	0	1.7
		Medium	88.2	2.0	4.9	4.9	39.4	18.6	34.7	7.3	30.4	29.7	22.2	17.7
		High	41.9	0	47.0	11.1	32.4	28.1	31.8	7.9	7.1	20.3	63.7	8.9

SEASON OF 1926–27

During the storage season of 1926–27, 3 lots of onions were studied, 2 of which were grown in the Middle West and 1 in the Northeast. The first 2 of these, referred to as lots 3 and 4, were midwestern- and eastern-grown, respectively, and were purchased on the local market October 16 and left in the workroom at Arlington Experiment Farm to dry off until October 18, when the onions of each variety were

sorted, thoroughly mixed, and apportioned into 18 slat crates holding a bushel each. Crate lots were put in storage in each of the nine temperature and humidity chambers already described. These were inspected on November 19 and January 20, and the results are recorded in table 2.

On November 23 another lot of midwestern-grown onions was purchased on the market and left in the workroom until the following day, when it was sorted, mixed, and stored similarly to the two other lots. This will be known as lot 5. Inspections of these onions were made on January 20 and March 21, and the results are shown in table 2.

RESULTS FOR SEASONS OF 1925-26 AND 1926-27

The results for the seasons of 1925–26 and 1926–27 are discussed separately from results obtained subsequently, because of the change in the adjustments of humidity relations in the later work.

A marked difference was seen in the keeping qualities of lots 1 and 2 (table 2). The superiority of lot 1 may be attributed to the fact that the bulbs were more mature when stored. After the inspection on February 16, lot 2 stored at the high humidities was discarded, since most of the onions had rooted and only a few dormant specimens were left. Figure 1 shows the average results after approximately 3 months' storage for the 5 lots of Yellow Globe onions studied during this time. A general study of these results shows the importance of both low temperature and low humidity in keeping onions dormant.

Dormancy.—In general the number of dormant onions remaining at each inspection showed a marked decrease at all temperatures as the humidity increased, and also a decrease as the temperature increased.

Sprouting.—Humidity did not seem to influence sprouting or top growth consistently. On the other hand there was an apparent general increase in sprouting at the two higher temperatures.

Rooting.—Root growth quite definitely increased at all storage temperatures as the humidity was increased, but there was no apparent relation to temperature except at the high humidity.

Decay.—Contrary to what might be expected, no consistent relation was found in the amount of decay, under the different storage conditions, to either temperature or humidity.

Loss in weight.—In table 3 is shown the progressive loss in weight in the sublots of lot 3 (midwestern) onions, which were not inspected but were weighed at certain periods during storage. This loss in weight, expressed in percentage, includes both the loss in water and in carbon dioxide given off through respiration activities. At all temperatures the loss decreased slightly as the humidities increased, as would be expected. The increasing loss as the storage temperatures increased can probably be explained as due to increasing transpiration and respiration.

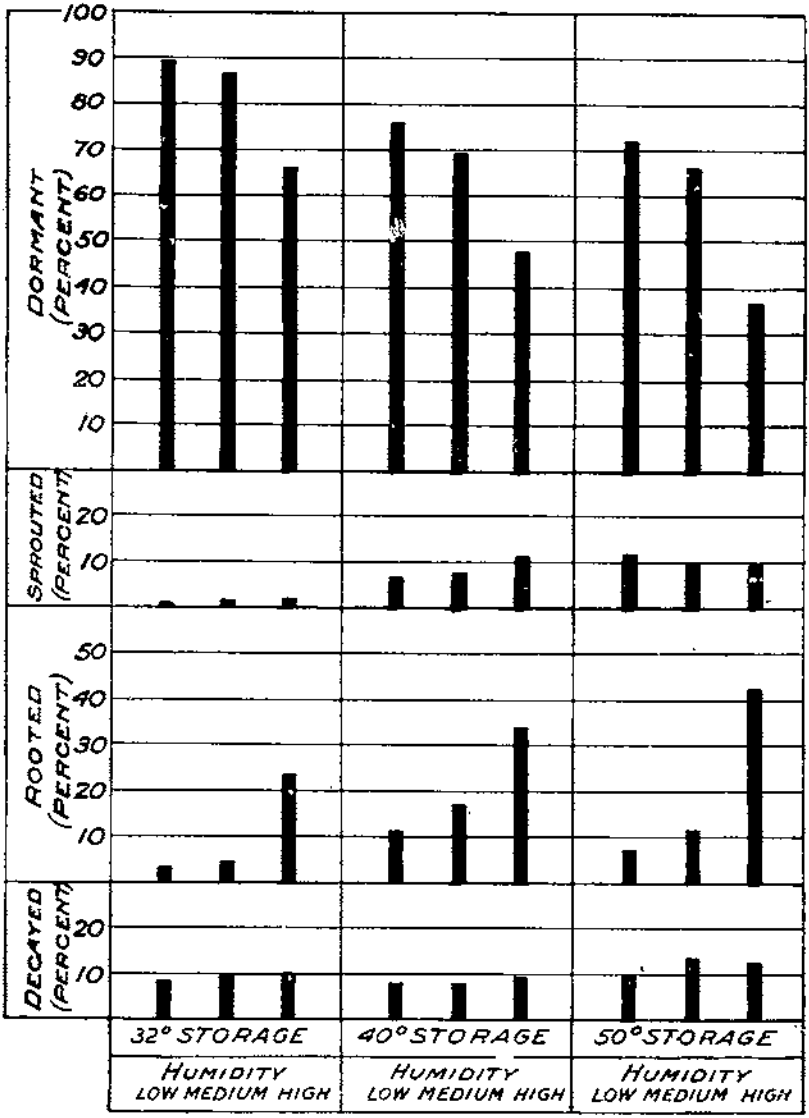

FIGURE 1.—Average condition (expressed in percentage) of 5 lots of Yellow Globe onions after approximately 3 to 4 months' storage at 32°, 40°, and 50° F., with low (65 percent), medium (80 percent), and high (90 percent) humidities at each temperature, for the seasons of 1925–26 and 1926–27.

TABLE 3.—*Cumulative loss in weight in midwestern onions during storage, season of 1926–27*

Weighing date	Storage temperature	Loss in weight at indicated humidity			Weighing date	Storage temperature	Loss in weight at indicated humidity		
		Low	Medium	High			Low	Medium	High
	° F.	Percent	Percent	Percent		° F.	Percent	Percent	Percent
Oct. 18	32	0.00	0.00	0.00	Oct. 18	50	0.00	0.00	0.00
Nov. 22		1.16	.99	.23	Nov. 22		2.13	1.53	1.16
Feb. 2		2.97	2.63	.87	Feb. 2		5.18	4.07	3.27
Mar. 23		4.97	4.39	2.93	Mar. 23		8.23	7.00	5.94
Oct. 18	40	0	0	0					
Nov. 22		1.80	1.57	1.24					
Feb. 2		4.35	4.13	2.90					
Mar. 23		6.78	6.44	5.25					

SEASON OF 1927–28

In the season of 1927–28 also, eastern- and midwestern-grown onions were selected, since it was desired to study each season onions grown under different climatic conditions. Midwestern onions designated as lot 1, which were secured on the Washington market on November 12, were well matured and dry. The following day they were sorted and mixed as usual, and duplicate lots were put into bushel slat crates and stored at 32°, 40°, and 50° F. However, as has been pointed out, the humidities in all the chambers were adjusted so that the same approximate saturation deficit would exist in corresponding chambers at the different temperatures (table 1). In addition to the chamber lots, eighteen 100-pound sacks of sorted and well-mixed onions were evenly divided and stacked in two rooms held at 32°, in order to compare onions stored in crates with those in sacks at both low and high humidities. The relative humidity of these rooms was maintained at approximately 60 and 90 percent, respectively.

The eastern-grown onions, designated as lot 2, were secured in Washington November 19 and taken direct from the railroad car in which they were shipped; being damp and not well cured, they were sorted and allowed to stand in crates in an airy location at Arlington Experiment Farm until November 23. On this date duplicate half-bushel hamper lots were put in storage in the control chambers, while the rest of the purchase was put into eight 1-bushel slat crates and ten 100-pound bags and divided between the 32° F. high (90 percent) and low (60 percent) humidity rooms in which the mid-western onions were stored.

Inspections were made on the lots of onions in the control chambers on January 9 and March 12, and the results are shown in table 4. Practically all of the midwestern-grown onions remained dormant except those in the high-humidity room held at 50° F., where considerable rooting occurred. The eastern-grown onions, on the other hand, showed somewhat more sprouting and root growth and considerably more decay, owing perhaps to less favorable climatic conditions for thorough curing.

The average temperature and humidity conditions actually maintained in the storage chambers for this season, as well as the succeeding seasons, are shown in table 5.

TABLE 4.—*Conditions found in Yellow Globe onions (seasons of 1927–28, 1928–29, and 1929–30) after storage for various periods at 32°, 40°, and 50° F., with low, medium, and high relative humidities having comparable saturation deficits (0.067, 0.037, and 0.016 inch of mercury, respectively)*

Year and lot no.	Storage period	Storage conditions		Keeping qualities of onions in indicated condition						Decay summary			Total loss in weight
		Temperature	Relative humidity	Dormant		Sprouted		Rooted		Neck rot	Other decay	Total	
				Sound	Decayed	Sound	Decayed	Sound	Decayed				
1927–28													
	Days	*° F.*		*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1 (midwestern)	57	32	Low	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
			Medium	99.5	.5	0	0	0	0	.5	0	.5	
			High	100.0	0	0	0	0	0	0	0	0	
		40	Low	100.0	0	0	0	0	0	0	0	0	
			Medium	99.5	.5	0	0	0	0	.5	0	.5	
			High	100.0	0	0	0	0	0	0	0	0	
		50	Low	99.5	.5	0	0	0	0	0	.5	.5	
			Medium	99.5	0	.5	0	0	0	0	0	0	
			High	97.5	.5	.5	0	1.5	0	.5	0	.5	
	109	32	Low	100.0	0	0	0	0	0	0	0	0	3.25
			Medium	99.5	.5	0	0	0	0	.5	0	.5	2.51
			High	100.0	0	0	0	0	0	0	0	0	1.32
		40	Low	100.0	0	0	0	0	0	0	0	0	3.75
			Medium	100.0	0	0	0	0	0	0	0	0	3.23
			High	91.5	0	0	0	8.5	0	0	0	0	1.09
		50	Low	99.5	.5	0	0	0	0	0	.5	.5	3.62
			Medium	98.5	1.0	.5	0	0	0	.6	.4	1	2.32
			High	48.0	2.1	.5	0	49.4	0	2.1	0	2.1	2.04
2 (eastern)	47	32	Low	100.0	0	0	0	0	0	0	0	0	
			Medium	95.0	3.7	0	1.3	0	0	5.0	0	5.0	
			High	92.8	7.2	0	0	0	0	4.3	2.9	7.2	
		40	Low	90.0	5.7	4.3	0	0	0	2.9	2.8	5.7	
			Medium	91.4	7.2	1.4	0	0	0	4.3	2.9	7.2	
			High	90.1	6.5	1.7	1.7	0	0	4.8	3.4	8.2	
		50	Low	79.5	13.5	0	0	4.1	2.9	13.7	2.7	16.4	
			Medium	79.5	8.2	5.5	6.8	0	0	11.0	4.0	15.0	
			High	77.0	7.2	2.9	7.2	2.9	2.8	11.6	5.6	17.2	
	110	32	Low	88.3	11.7	0	0	0	0	9.1	2.6	11.7	5.10
			Medium	76.7	20.5	1.4	1.4	0	0	20.5	1.4	21.9	3.95
			High	72.5	27.5	0	0	0	0	24.8	2.7	27.5	2.06
		40	Low	68.3	20.1	5.8	5.8	0	0	21.8	4.1	25.9	6.29

			Medium	65.3	23.2	5.8	4.3	1.4	0	24.7	2.8	27.5	2.95
			High	53.1	17.7	1.9	0.4	16.2	4.7	24.2	4.6	28.8	2.20
		50	Low	48.0	17.8	8.2	17.8	4.1	4.1	27.5	12.2	39.7	5.99
			Medium	50.7	24.7	13.7	10.9	0	0	34.3	1.3	35.6	4.95
			High	27.6	14.5	18.7	16	14.5	8.7	29.0	10.2	39.2	2.12
1928–29													
3 (midwestern)	75	32	Low	100.0	0	0	0	0	0	0	0	0	3.3
			Medium	96.0	2.0	2.0	0	0	0	2.0	0	2.0	1.2
			High	100.0	0	0	0	0	0	0	0	0	1.8
		40	Low	99.4	0	0	0	.6	0	0	0	0	3.8
			Medium	98.6	0	.7	0	.7	0	0	0	0	2.5
			High	83.3	0	2.5	0	13.6	.6	.5	6.0	1.1	2.1
		50	Low	92.3	0	6.1	.6	1.0	0	.6	0	.6	3.5
			Medium	89.8	.6	7.8	0	1.8	0	0	.6	.6	3.2
			High	70.6	.6	9.8	0	19.0	0	0	.6	.6	2.0
	117	32	Low	100.0	0	0	0	0	0	0	0	0	----------
			Medium	96.0	2.0	2.0	0	0	0	2.0	0	2.0	----------
			High	88.6	1.3	0	0	10.1	0	0	1.3	1.3	----------
		40	Low	98.1	0	1.3	0	.6	0	0	0	0	----------
			Medium	96.5	1.4	1.4	0	.7	0	1.4	0	1.4	----------
			High	58.0	.6	3.4	.6	36.8	.6	1.2	.6	1.8	----------
		50	Low	78.4	0	18.8	1.7	1.1	0	1.7	0	1.7	----------
			Medium	73.6	.6	22.2	0	3.6	0	0	.6	.6	----------
			High	32.0	2.0	25.5	0	40.5	0	1.3	.7	2.0	----------
4 (eastern)	58	32	Low	98.3	.4	0	0	0	1.3	.4	1.3	1.7	3.4
			Medium	95.0	0	5.0	0	0	0	0	0	0	2.5
			High	98.0	.5	1.0	0	.5	0	.5	0	.5	1.8
		40	Low	77.6	0	19.5	.6	1.7	.6	.6	.6	1.2	6.4
			Medium	75.8	.6	18.4	.6	4.6	0	1.2	0	1.2	3.4
			High	62.9	2.0	25.2	0	9.9	0	.5	.5	2.0	.9
		50	Low	53.6	1.3	42.5	2.8	0	0	3.4	.7	4.1	3.6
			Medium	49.8	1.6	37.5	2.1	9.0	0	2.1	1.6	3.7	3.3
			High	31.5	2.5	45.0	3.1	17.3	.6	4.9	1.3	6.2	2.4
	100	32	Low	95.4	1.4	1.8	0	0	1.4	1.4	1.4	2.8	----------
			Medium	88.2	0	11.8	0	0	0	0	0	0	----------
			High	84.0	.6	7.0	0	8.4	0	.6	0	.6	----------
		40	Low	65.0	0	4.8	1.1	28.5	.6	1.1	.6	1.7	----------
			Medium	66.0	0	20.7	.6	12.7	0	.6	0	.6	----------
			High	29.0	4.0	36.2	4.0	26.8	0	5.9	2.1	8.0	----------
		50	Low	34.8	1.2	61.2	2.8	0	0	3.4	.6	4.0	----------
			Medium	29.0	2.4	53.0	4.5	11.1	0	4.8	2.1	6.9	----------
			High	14.2	2.5	56.3	7.4	19.0	.6	7.4	3.1	10.5	----------

TABLE 4.—*Conditions found in Yellow Globe onions (seasons of 1927–28, 1928–29, and 1929–30) after storage for various periods at 32°, 40°, and 50° F., with low, medium, and high relative humidities having comparable saturation deficits (0.067, 0.037, and 0.016 inch of mercury, respectively)*—Continued

Year and lot no.	Storage period	Storage conditions		Keeping qualities of onions in indicated condition						Decay summary			Total loss in weight
		Temperature	Relative humidity	Dormant		Sprouted		Rooted		Neck rot	Other decay	Total	
				Sound	Decayed	Sound	Decayed	Sound	Decayed				
1929–30													
	Days	° *F.*		*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
5 (midwestern)	61	32	Low	98.4	0.8	0	0.8	0	0	1.6	0	1.6	4.7
			Medium	95.6	1.4	0	0	2.5	.5	.7	1.2	1.9	3.8
			High	90.3	1.6	.7	0	7.4	0	.8	.8	1.6	2.8
		40	Low	89.6	.7	7.4	0	2.3	0	.7	0	.7	4.7
			Medium	81.8	5.6	4.2	0	6.3	2.1	2.8	4.9	7.7	4.0
			High	66.6	3.5	4.4	0	24.1	1.4	2.1	2.8	4.9	2.3
		50	Low	73.7	0	13.8	.8	11.7	0	.8	0	.8	3.7
			Medium	82.7	1.2	6.1	0	10.0	0	.7	.5	1.2	3.8
			High	39.0	2.8	6.4	1.4	49.6	.8	4.2	0	4.2	1.9
	93	32	Low	95.8	1.6	.8	.8	0	0	1.6	.8	2.4	.5
			Medium	95.6	1.4	0	0	2.5	.5	.7	1.2	1.9	5.1
			High	89.0	1.6	1.4	0	8.0	0	.8	.8	1.6	5.3
		40	Low	73.3	1.4	8.5	0	16.8	0	1.4	0	1.4	5.7
			Medium	70.4	5.6	7.1	0	14.8	2.1	2.8	4.9	7.7	5.0
			High	46.5	3.5	14.6	0	34.0	1.4	2.1	2.8	4.9	3.7
		50	Low	55.7	2.1	27.6	.8	13.8	0	2.9	0	2.9	6.0
			Medium	64.8	1.5	15.4	3.0	14.6	.7	3.1	2.1	5.2	6.1
			High	19.3	3.5	13.5	1.4	61.5	.8	5.7	0	5.7	2.9

TABLE 5.—*Average temperatures and relative humidities maintained in storage chambers during the seasons of 1927–28, 1928–29, and 1929–30*

Storage season	Storage conditions with—					
	Low humidity		Medium humidity		High humidity	
	Temperature	Humidity	Temperature	Humidity	Temperature	Humidity
	°F.	Percent	°F.	Percent	°F.	Percent
1927–28	32.6	66.6	31.5	79.7	31.7	88.0
	40.2	71.5	40.2	83.8	40.3	94.2
	49.4	80.6	48.7	90.5	49.8	96.0
1928–29	33.6	68.5	32.5	79.0	32.6	89.0
	40.8	74.4	40.8	84.7	41.5	95.2
	49.5	83.0	49.4	89.4	50.9	98.4
1929–30	33.4	64.0	32.4	78.0	32.2	89.0
	40.9	74.0	40.9	88.0	41.9	94.0
	50.0	84.0	50.0	90.0	50.2	98.0

The onions stored in 100-pound sacks and bushel crates at 32° F. with high and low relative humidities were inspected only on March 12. The midwestern onions, both those in sacks and those in crates, showed no sprouting or rooting and less than 0.1 percent decay at either humidity. The average percentage loss in weight per sack was 1.54 and 0.81 for low and high humidities, respectively. The inspection results on the eastern onions stored in sacks and crates at high and low relative humidity at 32° are shown in table 6. These results indicate little difference between sack and crate storage at the low humidity, but the crated onions at the high humidity did show slightly less decay and slightly more rooting but no difference in sprouting, as compared with the sacked lot.

TABLE 6.—*Average condition and weight loss in sacked and crated lots of eastern-grown Yellow Globe onions after 109 days' storage at 32° F., with high and low relative humidities, season of 1927–28*

Relative humidity	Containers	Keeping qualities of onions in indicated condition						Decay summary			Total loss in weight
		Dormant		Sprouted		Rooted					
		Sound	Decayed	Sound	Decayed	Sound	Decayed	Neck rot	Other decay	Total	
		Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
Low	Sacks	82.8	16.5	0.7	0.0	0.0	0.0	14.7	1.8	16.5	4.25
High	do	75.6	22.8	.4	.2	.9	.1	20.9	2.2	23.1	1.36
Low	Crates	84.6	14.9	.2	.3	0	0	13.3	1.9	15.2	4.66
High	do	81.1	17.1	.4	.3	1.1	0	16.2	1.2	17.4	2.54

SEASON OF 1928–29

Midwestern- and eastern-grown onions were stored during the season of 1928–29 also. The midwestern onions, designated as lot 3 (table 4), were secured on the Washington market on October 19. The following day they were sorted and 18 half-bushel hamper lots were prepared in duplicate and put in each of the humidity chambers, one lot for periodic inspection and the other for determining the weight

loss. The remaining onions were weighed into twelve 100-pound bags which were stored at 32° F., 6 of them with low and 6 with high relative humidity.

The eastern-grown onions, designated as lot 4, were purchased on the Washington market on November 1 but were not placed in the humidity chambers until November 6, when 12 bags of these also were stored at 32° F., 6 with low and 6 with high relative humidity.

The usual inspections were made on the lots in the humidity chambers on January 3 and February 14; the results are included in table 4. The average temperature and humidity conditions actually maintained during the storage season are given in table 5.

The bag lots stored at 32° F. with low and high relative humidities were again weighed and inspected on March 15. The results, expressed in percentages, are given in table 7.

TABLE 7.—*Average condition and weight loss in sacked lots of midwestern- and eastern-grown Yellow Globe onions after 129 days' storage at an average temperature of 32.2° F., and relative humidities averaging 61.4 and 84.5 percent, season of 1928–29*

Lot	Relative humidity	Keeping qualities of onions in indicated condition					
		Dormant		Sprouted		Rooted	
		Sound	Decayed	Sound	Decayed	Sound	Decayed
		Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Midwestern	Low	91.9	1.8	3.9	0.4	2.0	0.0
	High	83.0	2.8	2.4	.6	11.0	.2
Eastern	Low	97.2	1.2	0	.3	1.3	0
	High	92.6	1.8	.2	.0	5.4	0

Lot	Relative humidity	Decay summary			Shrinkage by weight		
		Neck rot	Slimy soft rot	Total	Culls	Water loss	Total
		Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Midwestern	Low	1.2	1.0	2.2	2.5	3.8	6.3
	High	2.2	1.4	3.6	6.9	1.9	8.8
Eastern	Low	.4	1.1	1.5	9.8	5.4	15.2
	High	.4	1.4	1.8	15.2	3.3	18.5

SEASON OF 1929–30

One lot of Yellow Globe onions, designated as lot 5, was studied during the season of 1929–30. They were well-matured midwestern-grown onions purchased on November 26 on the Washington market. The following day they were sorted and divided into 18 half-bushel hampers and ten 100-pound bags. The hamper lots were placed in duplicate in the various humidity chambers and the bags were stored at 32° F., 5 with low and 5 with high humidity.

The onions stored in hampers were inspected on January 27 and February 28 after 61 and 93 days' storage, respectively, the results being given in table 4.

The sacked lots of onions were inspected after 93 days' storage at 32° F. with high and low relative humidities, the results being shown in table 8. The average temperature and humidity conditions main-

tained during the storage season, from November 26 to March 20, are shown in table 5.

TABLE 8.—*Average condition and weight loss on March 20 on inspection of sacked lots of midwestern-grown Yellow Globe onions after 93 days' storage at an average temperature of 32.4° F., and relative humidities of 64 and 81 percent, season of 1929–30*

Relative humidity	Keeping qualities of onions in indicated condition					
	Dormant		Sprouted		Rooted	
	Sound	Decayed	Sound	Decayed	Sound	Decayed
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Low	94.5	2.5	1.2	0.1	0.6	1.2
High	87.0	3.2	2.1	.2	6.3	1.0

Relative humidity	Decay summary				Shrinkage by weight		
	Neck rot	Slimy soft rot	Brown spot [1]	Total decay	Water loss	Culls	Total
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Low	2.6	0.1	1.1	3.8	4.7	4.5	9.2
High	4.2	.1	.1	4.4	2.5	12.6	15.1

[1] Brown spot was a firm decay found in certain lots of onions. Bacteria were isolated from these tissues, but a causal relation was not established.

RESULTS FOR SEASONS OF 1927–28, 1928–29, AND 1929–30

The results of inspections of the 5 lots studied during this period are given in table 4, and the averaged results after approximately 3 months' storage are shown graphically in figure 2. By adjusting the relative humidity to maintain comparable saturation deficits in the low-, medium-, and high-humidity chambers at the three temperatures, an entirely different interrelation of humidities to temperatures was disclosed. In table 5 is shown the average seasonal temperatures and humidities actually maintained. At temperatures above 32° F. all the humidities were materially higher than during the first two seasons' work (1925–26 and 1926–27), especially in the low-humidity group. However, the relations of temperature and humidity to condition at inspection remained practically the same as in the first two seasons.

Dormancy.—The several lots of onions differing in condition before going into storage showed considerable difference in keeping quality. The percentage of specimens remaining dormant after each inspection, however, tended to decrease more or less uniformly with the increase in relative humidity, especially as the storage temperature increased. In most instances the percentage of dormancy at the 50° F. storage with low humidity was greater than at 40° with high humidity. In the sacked lots stored at 32° F. with low and high humidities and stacked to correspond with commercial conditions, the effect of increased humidity in increasing the amount of rooting was more marked than in the lots stored in the smaller chambers. Probably this was owing to the restricted aeration caused by the close piling of the sacks, which caused a higher humidity and possibly a higher temperature around the onions.

Sprouting.—As has been pointed out (p. 7) the amount of sprouting did not vary consistently with the humidity, but it did increase with the storage temperature irrespective of the humidity. The amount of

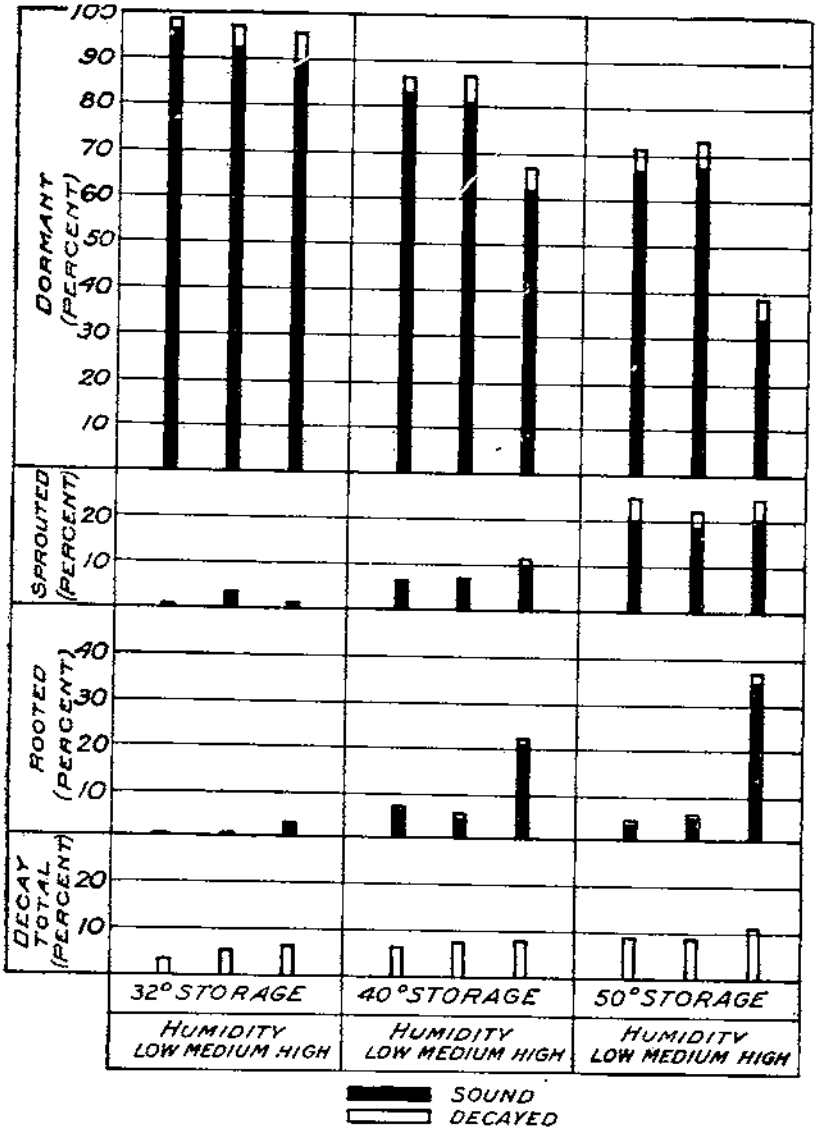

FIGURE 2.—Average condition (expressed in percentage) of 5 lots of Yellow Globe onions after approximately 3 to 4 months' storage at 32°, 40°, and 50° F., with low, medium, and high humidities having comparable saturation deficits (0.067, 0.037, and 0.016 inch of mercury) for the seasons of 1927–28, 1928–29, and 1929–30.

sprouting was usually negligible at the two lower temperatures but became important at 50° F.

Rooting.—The amount of rooting showed a definite increase as the humidity increased. There was also a general increase in rooting as

the storage temperature increased, but even at 50° F. with low humidity the amount of rooting was never excessive.

Decay.—Beginning in 1927–28, at each inspection all decayed specimens were examined and classified as dormant, sprouting, or rooting; in addition the type of decay present was reported as neck rot, which is the most frequent source of loss in storage onions, or as other decay. The preponderance of decay was found to be neck rot, but a small amount of slimy soft rot was occasionally found. Other kinds of decay occurred so infrequently that they were not classified. While the total amount of decay in storage did not vary altogether consistently with the humidity, there seemed to be a slight increase with increased humidity. On the other hand there was a general increase in decay with the increase in storage temperature, irrespective of humidity.

WHITE GLOBE

White Globe onions are usually considered comparatively poor keepers. They must be cured more carefully than the yellow varieties because of their greater susceptibility to decay, which not only destroys the specimens that become infected but also is likely to stain or discolor other onions with which the infected specimens are in contact. To bring the best price these onions must be sound and without discoloration or stain.

SEASON OF 1925–26

For study during the season of 1925–26 a lot of White Globe onions was purchased on the Washington market on November 11. They were put into slat crates and left in the workroom at Arlington Experiment Farm until November 18, when they were sorted, mixed, apportioned into half-bushel hampers, and stored in the various temperature and humidity chambers already described. Inspections were made on January 7 and February 16. Detailed results are shown under lot 1 in table 9.

SEASON OF 1926–27

The onions used for storage experiments during the season of 1926–27 were purchased on the Washington market October 16 and left in slat crates until October 18, when they were sorted as usual and stored in half-bushel hampers. Inspections were made on November 19 and January 20, and the results are shown under lot 2 in table 9.

SEASON OF 1927–28

The onions used during the season of 1927–28 were purchased in Washington November 7 and left in the workroom at Arlington Experiment Farm until November 8, when they were sorted as usual and stored in half-bushel hampers in the various temperature and humidity chambers. Inspections were made on January 9 and March 12, and the results are shown under lot 1 in table 10.

SEASON OF 1929–30

The onions used during the season of 1929–30 were purchased in Washington on November 26 and on the following day were sorted and stored in half-bushel hampers under the various conditions of temperature and humidity. Inspections were made on January 27 and February 28, and the results are shown under lot 2 in table 10.

TABLE 9.—*Conditions found in White Globe onions (seasons of 1925–26 and 1926–27) after storage for various periods at 32°, 40°, and 50° F., with low (65 percent), medium (80 percent), and high (90 percent) relative humidities at each temperature*

Year and lot no.	Storage period	Relative humidity	Condition after storage at indicated temperature											
			32° F.				40° F.				50° F.			
			Dormant	Sprouted	Rooted	Decayed	Dormant	Sprouted	Rooted	Decayed	Dormant	Sprouted	Rooted	Decayed
1925–26	*Days*		*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1	50	Low	93.2	1.6	4.0	1.2	82.3	1.5	13.8	2.4	62.8	1.6	26.0	9.6
		Medium	86.0	2.4	6.0	5.6	68.4	1.9	27.5	2.2	49.7	2.8	42.6	4.9
		High	63.6	1.1	31.6	3.7	38.3	5.7	50.3	5.7	23.2	6.3	38.3	32.2
	90	Low	91.2	1.6	4.0	3.2	72.7	3.0	19.5	4.8	48.4	6.8	33.6	11.2
		Medium	81.6	2.4	7.6	8.4	49.6	6.2	40.5	3.7	41.7	6.1	44.0	8.2
		High	27.2	1.1	66.9	4.8	4.7	7.5	69.8	18.0	7.3	7.3	47.4	38.0
1926–27														
2	32	Low	94.4	0	0	5.6	93.2	0	0	6.8	86.8	.6	0	12.6
		Medium	95.5	0	0	4.5	86.6	.6	1.9	10.9	83.0	1.2	1.8	14.0
		High	83.0	0	3.7	13.3	63.6	0	24.7	11.7	50.0	0	26.3	23.7
	94	Low	59.4	0	0	40.6	66.7	0	0	33.3	59.4	1.2	0	39.4
		Medium	59.0	0	0	41.0	56.2	.7	4.1	39.0	39.8	6.2	3.1	50.9
		High	48.4	0	3.9	47.7	25.6	1.3	38.2	34.9	16.4	3.9	33.0	46.7

TABLE 10.—*Conditions found in 2 lots of White Globe onions (seasons of 1927–28 and 1929–30) after storage for various periods at 32°, 40°, and 50° F., with low, medium, and high relative humidities having comparable saturation deficits (0.067, 0.037, and 0.016 inch of mercury)*

Year and lot no.	After storage for—	Storage conditions		Keeping qualities of onions in indicated condition						Decay summary			Loss in weight
		Temperature	Relative humidity	Dormant		Sprouted		Rooted		Neck rot	Other decay	Total	
				Sound	Decayed	Sound	Decayed	Sound	Decayed				
1927–28	*Days*	°F.		*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1	62	32	Low	84.6	15.4	0.0	0.0	0.0	0.0	14.3	1.1	15.4	3.11
			Medium	82.7	17.3	0	0	0	0	14.5	2.8	17.3	2.04
			High	77.3	22.7	0	0	0	0	20.4	2.3	22.7	1.14
		40	Low	61.0	39.0	0	0	0	0	36.6	2.4	39.0	3.77
			Medium	70.1	27.6	0	2.3	0	0	28.8	1.1	29.9	3.80
			High	51.7	39.5	0	2.2	2.2	4.4	44.0	2.1	46.1	1.97
		50	Low	42.2	55.4	0	2.4	0	0	55.4	2.4	57.8	9.07
			Medium	31.3	54.5	0	2.0	3.1	9.1	64.5	1.1	65.6	3.92
			High	26.7	56.0	0	0	1.3	16.0	70.5	1.5	72.0	4.30
	125	32	Low	61.5	38.5	0	0	0	0	36.3	2.2	38.5	8.02
			Medium	62.3	37.7	0	0	0	0	31.9	5.8	37.7	4.46
			High	58.0	42.0	0	0	0	0	35.2	6.8	42.0	3.41
		40	Low	30.5	64.6	1.2	2.4	0	1.3	57.3	11.0	68.3	11.70
			Medium	41.4	51.7	1.2	4.6	1.1	0	50.0	6.3	56.3	9.23
			High	18.7	51.6	0	2.2	8.8	18.7	70.3	2.2	72.5	5.64
		50	Low	14.5	79.5	0	6.0	0	0	79.6	5.9	85.5	18.50
			Medium	6.1	67.7	1.1	5.0	3.0	17.1	88.0	1.8	89.8	11.70
			High	2.7	64.0	0	0	2.6	30.7	90.7	4.0	94.7	12.60
1929–30													
2	61	32	Low	75.9	16.3	3.0	2.6	1.3	0	18.9	0	18.9	----------
			Medium	74.0	10.8	2.5	1.3	11.4	0	12.1	0	12.1	----------
			High	70.5	15.1	2.9	3.6	7.9	0	18.7	0	18.7	----------
		40	Low	65.8	17.1	10.3	3.4	2.0	1.4	21.9	0	21.9	----------
			Medium	65.3	11.7	8.6	.9	11.1	2.4	14.2	.8	15.0	----------
			High	47.5	18.6	6.4	3.2	15.4	8.9	27.6	3.1	30.7	----------
		50	Low	50.0	14.5	9.2	9.9	14.5	1.9	26.3	0	26.3	----------
			Medium	47.7	11.1	14.4	7.9	16.3	2.6	21.6	0	21.6	----------
			High	31.4	9.6	10.9	5.2	28.8	14.1	27.6	1.3	28.9	----------
	93	32	Low	65.5	26.8	3.8	2.6	1.3	0	29.4	0	29.4	----------
			Medium	68.3	13.9	5.1	1.3	11.4	0	15.2	0	15.2	----------
			High	65.5	19.4	2.9	3.6	8.6	0	23.0	0	23.0	----------
		40	Low	57.5	18.5	15.7	4.8	2.1	1.4	24.7	0	24.7	----------
			Medium	54.4	13.6	9.2	1.8	17.3	3.7	18.3	.8	19.1	----------
			High	34.6	21.8	8.3	3.8	21.8	9.7	32.2	3.1	35.3	----------
		50	Low	30.5	19.8	18.4	14.8	14.5	2.0	36.6	0	36.6	----------
			Medium	34.0	13.7	22.0	9.6	17.0	3.7	27.0	0	27.0	----------
			High	12.8	11.5	16.0	5.8	37.2	16.7	32.7	1.3	34.0	----------

RESULTS

A comprehensive summary of the storage results for White Globe onions is given in figures 3 and 4. Figure 3 shows the averaged results

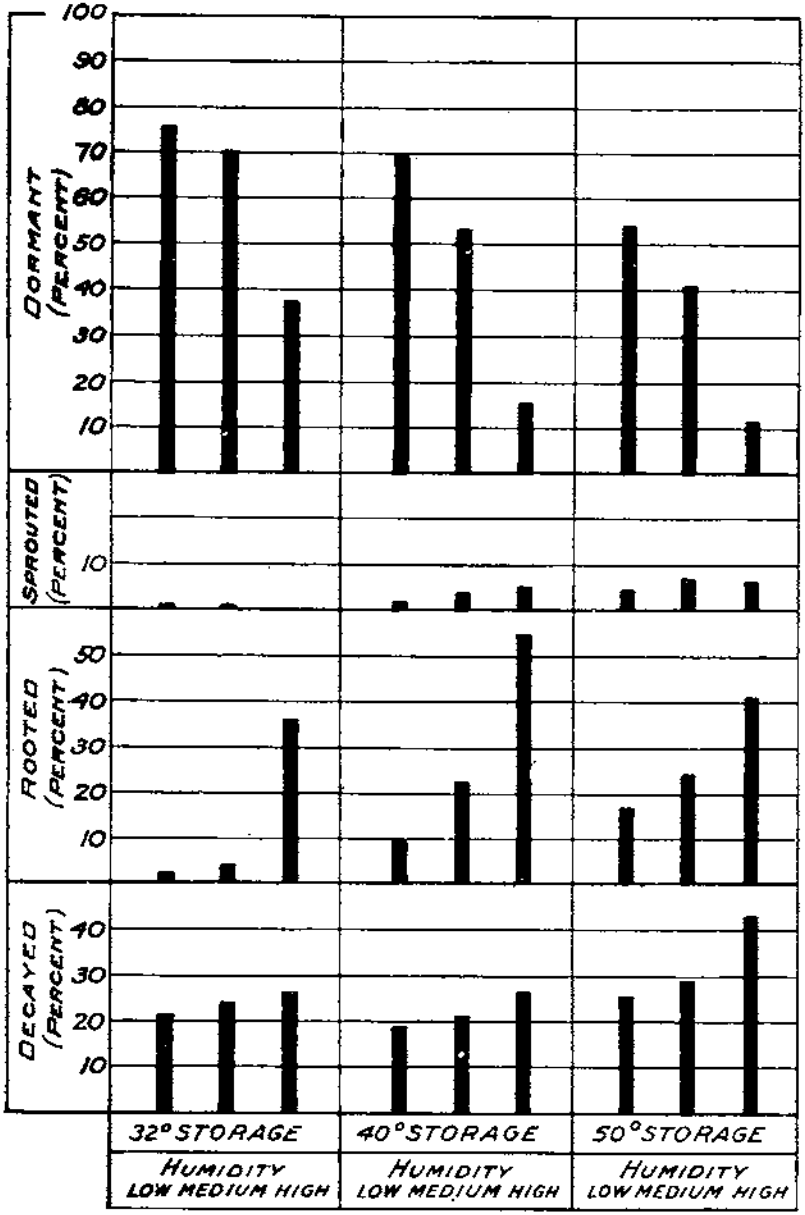

FIGURE 3.—Average condition (expressed in percentage) of 5 lots of White Globe onions after approximately 3 months' storage at 32°, 40°, and 50° F., with low (65 percent), medium (80 percent), and high (90 percent) relative humidities at each storage temperature, seasons of 1925–26 and 1926–27.

of all lots for the 1925–26 and 1926–27 seasons after approximately 3 months' storage, which probably represents about the maximum

storage period for a large part of the commercial crop, while figure 4 shows the results of all lots for the seasons of 1927–28 and 1928–29 after the same storage period. It will be recalled that during the first two seasons the same humidities were maintained at the different

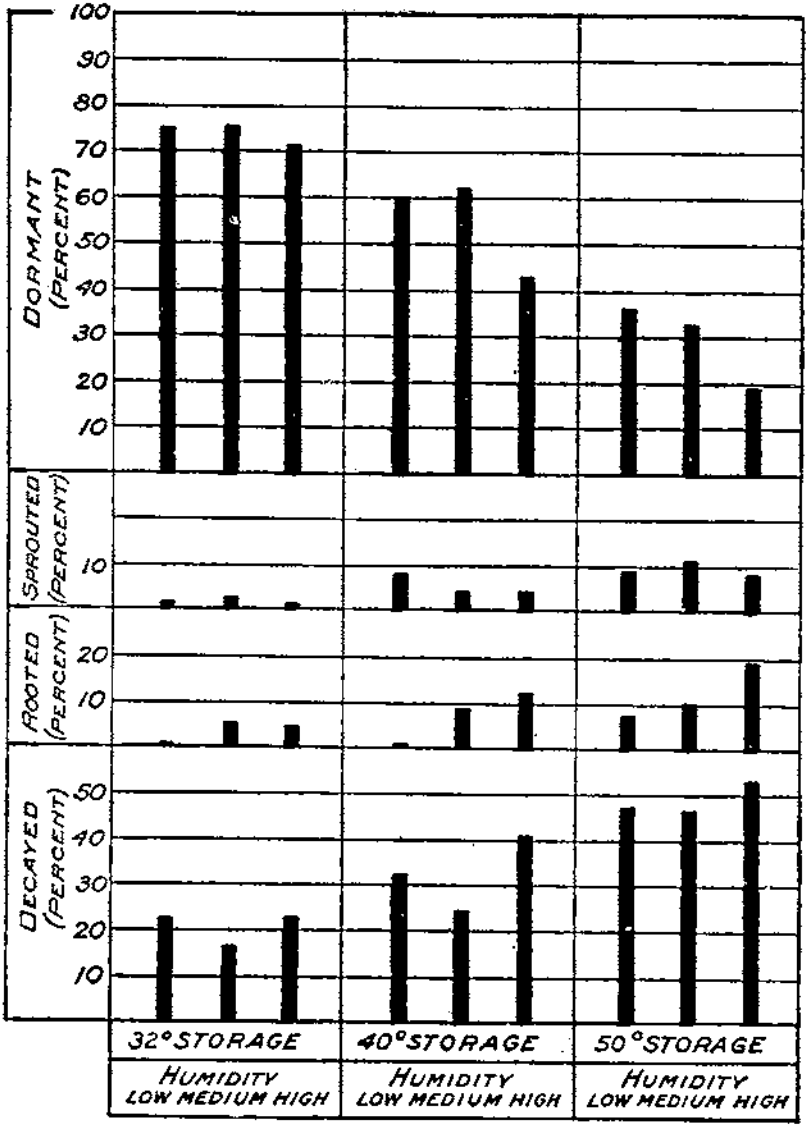

FIGURE 4.—Average condition (expressed in percentage) of 5 lots of White Globe onions after approximately 3 months' storage at 32°, 40°, and 50° F., with low, medium, and high relative humidities having comparable saturation deficits (0.007, 0.037, and 0.010 inch of mercury), seasons of 1927–28 and 1929–30.

storage temperatures, whereas in subsequent years the same saturation deficits were maintained.

Tables 9 and 10 indicate rather definitely that even under identical conditions White Globe onions did not keep as long in storage as the

Yellow Globe. Even when stored under the most favorable conditions (32° F. with low humidity) these onions usually cannot be expected to keep in a moderately salable condition longer than 2 months. In commercial practice it is seldom possible to maintain storage conditions as favorable as those maintained under the experimental conditions described herein. Therefore, the commercial-storage life of these onions undoubtedly is often shorter than the storage life indicated above. The condensed data in figures 3 and 4 indicate that the amount of sprouting, while almost negligible, increased very slightly with an increase in storage temperature. Root growth tended to increase with the humidity and generally with the temperature. Decay did not consistently increase with either the temperature or humidity, but there appeared to be a slightly greater development at the higher temperatures and humidities. The average decay was considerably greater in these onions than in the yellow type stored under the same conditions and for approximately the same periods of time. Most of this decay was classed as neck rot.

VALENCIA

One lot of Valencia onions grown in Walla Walla County, Wash., was received at the laboratory on November 8, 1925, having been purchased on the market in Chicago on November 6 out of a shipment that had just arrived from the grower. It is quite probable that these were harvested just before shipment. After standing in slat crates in the workroom at Arlington Experiment Farm until November 11, the onions were placed in hampers and put in the storage chambers at various temperatures and humidities. Inspections were made on December 1 and January 7. On September 18, 1926, another lot from the same source was purchased in Chicago and sent to the laboratory, where the onions were put in storage on September 20. These onions were inspected on November 19. The results of each inspection are shown in table 11.

The combined results from the 2 years' storage tests indicate that from a commercial viewpoint Valencia onions from the Walla Walla district cannot be expected to keep profitably much longer than 1 to 2 months. These onions are very succulent when harvested, and owing to local high temperatures and humidities the bulbs do not have optimum conditions for satisfactory curing after harvest. Therefore, they are usually consumed soon after they are harvested. It will be noted that decay was found to be relatively limited during storage, most of the loss being due to root growth, even at the lowest temperature.

On October 15, 1930, some Valencia onions grown in Colorado were purchased just after arrival on the Washington, D. C., market and half-bushel basket lots were apportioned out and put in the nine storage chambers. These onions appeared to be well matured, firm, and suitable for prolonged storage. They were inspected on December 15 and January 15 with the results shown in table 12. After 3 months' storage at 32° F. with all humidities and at 40° and 50° with low humidity, there was in each case less than 5 percent total loss. The actual humidities maintained are shown in table 5. It will be noted that comparatively little decay or sprouting developed in any of the conditions and that the principal loss occurred through rooting.

TABLE 11.—*Conditions found in Washington-grown Valencia onions after storage for various periods at 32°, 40°, and 50° F., with low (65 percent), medium (80 percent), and high (90 percent) relative humidities (seasons of 1925–26 and 1926–27)*

Year and lot no.	Storage period	Relative humidity	Condition after storage at indicated temperature											
			32° F.				40° F.				50° F.			
			Dormant	Sprouted	Rooted	Decayed	Dormant	Sprouted	Rooted	Decayed	Dormant	Sprouted	Rooted	Decayed
1925–26	*Days*		*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1	20	Low	76.7	0.0	20.5	2.8	74.0	0.0	26.0	0.0	69.0	0.0	37.8	2.2
		Medium	78.0	0	22.0	0	67.4	0	32.6	0	63.6	0	36.4	0
		High	59.0	0	41.0	0	66.3	.4	33.3	0	50.1	0	49.9	0
	57	Low	73.1	0	22.3	4.6	61.0	2.0	37.0	0	39.1	2.2	57.8	.9
		Medium	76.2	0	23.8	0	43.9	2.2	53.4	.5	37.0	1.7	61.3	0
		High	19.5	0	80.5	0	35.6	1.1	62.6	.7	17.5	1.5	79.5	1.5
1926–27														
2	60	Low	86.3	3.9	9.8	0	51.0	20.5	26.5	2.0	55.3	28.9	0	15.8
		Medium	56.1	17.1	19.5	7.3	15.9	22.8	47.7	13.6	40.0	12.5	27.5	20.0
		High	0	4.5	72.7	22.8	0	25.9	59.3	14.8	0	16.4	32.6	51.0

These results indicate that well-matured onions of the Valencia type grown in the Colorado section can be expected to keep in storage equally as well as the best of the Yellow Globe type.

TABLE 12.—*Conditions found in Colorado-grown Valencia onions (season of 1930–31) after storage for various periods at 32°, 40°, and 50° F., with low, medium, and high relative humidities having comparable saturation deficits (0.067, 0.037, and 0.016 inch of mercury)*

Storage period	Storage conditions		Keeping qualities of onions in indicated condition						Decay summary		
			Dormant		Sprouted		Rooted		Neck rot	Other decay	Total
	Temperature	Relative humidity	Sound	Decayed	Sound	Decayed	Sound	Decayed			
Days	*°F.*		*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
61	32	Low	100.0	0.0	0	0	0.0	0.0	0.0	0.0	0.0
		Medium	97.8	2.2	0	0	0	0	2.2	0	2.2
		High	98.0	0	0	0	2.0	0	0	0	0
	40	Low	96.0	2.0	0	0	0	2.0	0	4.0	4.0
		Medium	66.7	0	0	0	33.3	0	0	0	0
		High	63.4	2.5	0	0	34.1	0	0	2.5	2.5
	50	Low	93.0	0	0	0	7.0	0	0	0	0
		Medium	68.2	0	0	0	31.8	0	0	0	0
		High	42.6	0	0	0	55.3	2.1	0	2.1	2.1
92	32	Low	100.0	0	0	0	0	0	0	0	0
		Medium	97.8	2.2	0	0	0	0	0	0	0
		High	96.5	0	0	0	3.5	0	0	0	0
	40	Low	92.0	2.0	0	0	4.0	2.0	0	4.0	4.0
		Medium	58.7	2.2	0	0	39.1	0	2.2	0	2.2
		High	48.8	2.5	0	0	48.7	0	0	2.5	2.5
	50	Low	93.0	0	0	0	7.0	0	0	0	0
		Medium	25.0	0	0	0	75.0	0	0	0	0
		High	0.4	0	0	0	91.5	2.1	0	2.1	2.1

The difference in the reactions of the Valencia onions from these two localities is thought to be due to climatic differences during growth and harvest. In the Walla Walla district of Washington these onions are grown under hot, humid climatic conditions, resulting in a very succulent product. After harvest they are not given an opportunity to cure out well, but are shipped soon after they are pulled. In the Colorado section the growing conditions include a cooler, drier climate producing a drier, firmer onion, which, when cured under the prevailing dry atmosphere, is more suitable for storage.

BERMUDA (AMERICAN GROWN)

On May 27, 1930, some well-matured Bermuda onions grown in Texas were stored in half-bushel hampers under the usual nine temperature and humidity conditions. Inspections were made monthly until July 25, and the results (table 13) indicate that these onions stored at 32° F. with low and medium humidities kept in good condition for 2 months. At the higher temperatures deterioration was rapid and even at 40° with low humidity they kept well for only 1 month. In all lots most of the loss was due to rooting, which increased rapidly as the humidity increased. After the July 25 inspection all lots were discarded except those from 32° with low humidity. The dormant onions were returned and kept until August 25, when 98 percent were found to be still dormant.

TABLE 13.—*Conditions found in Texas-grown Bermuda onions after storage for various periods at 32°, 40°, and 50° F., with low (65 percent), medium (80 percent), and high (90 percent) relative humidities in 1930*

Storage period	Storage conditions		Keeping qualities of onions in indicated condition						Decay summary		
	Temperature	Relative humidity	Dormant		Sprouted		Rooted		Neck rot	Other decay	Total
			Sound	Decayed	Sound	Decayed	Sound	Decayed			
Days	*° F.*		*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
30	32	Low	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Medium	98.0	2.0	0	0	0	0	1.0	1.0	2.0
		High	98.0	0	0	0	2.0	0	0	0	0
	40	Low	90.0	0	0	0	10.0	0	0	0	0
		Medium	31.1	0	2.0	0	63.0	3.9	3.9	0	3.9
		High	26.7	1.9	1.0	0	69.5	.9	2.8	0	2.8
	50	Low	40.6	.2	9.9	0	47.7	.9	1.8	0	1.8
		Medium	10.4	1.0	3.8	0	75.0	3.8	4.8	0	4.8
		High	3.0	0	15.0	3.0	68.0	11.0	14.0	0	14.0
59	32	Low	100.0	0	0	0	0	0	0	0	0
		Medium	91.0	1.8	0	.5	6.7	0	1.0	1.3	2.3
		High	86.8	0	0	0	13.2	0	0	0	0
	40	Low	26.0	0	13.8	.9	58.4	0	.9	0	.9
		Medium	0	0	20.8	.9	77.3	.9	1.9	0	1.8
		High	0	1.9	9.5	.9	85.8	1.9	4.7	0	4.7
	50	Low	11.8	.9	23.4	0	63.0	.9	1.8	0	1.8
		Medium	3.8	1.0	15.4	0	76.0	3.8	4.8	0	4.8
		High [1]									

[1] Onions discarded.

ONION SETS

During the seasons of 1928–29 and 1929–30 onion sets of the Yellow Strasburg, Red Wethersfield, and White Portugal varieties, which for brevity will hereafter be referred to simply as yellow, red, and white sets, were stored under the conditions already described.

The sets used in the 1929–30 season were Wisconsin-grown and were harvested between September 3 and 13. After curing for 6 weeks in the field, the usual commercial practice, they were shipped to a storage warehouse in Chicago. Here the storage lots were purchased and shipped by express to the laboratory at Arlington Experiment Farm, arriving on October 6. In order to store them in the restricted space allowed in the metal chambers, special slat-bottom trays 18 inches square by 4 inches deep were built to simulate as nearly as possible the type of trays used in commercial onion-set storage houses. These commercial trays are usually about 3 feet square by 4 inches deep. On arrival of the yellow and red sets each lot was well mixed and placed in the trays, care being taken not to fill them to the top in order to insure air circulation over the tops of the sets when the trays were stacked.

SEASON OF 1928–29

During the season of 1928–29, in order to allow the sets to dry out, trays of each variety were stacked in the workroom until October 10, when a tray of each variety was stored in each chamber. The contents of the other nine trays of each variety, after being carefully hand-sorted to remove all decayed or injured specimens, were likewise stored. The unsorted lot of each variety will be referred to as "field-run"; the other lot will be designated as "hand-

sorted." Only a field-run lot of white sets was studied, and these were mixed and handled in the same manner as the other sets.

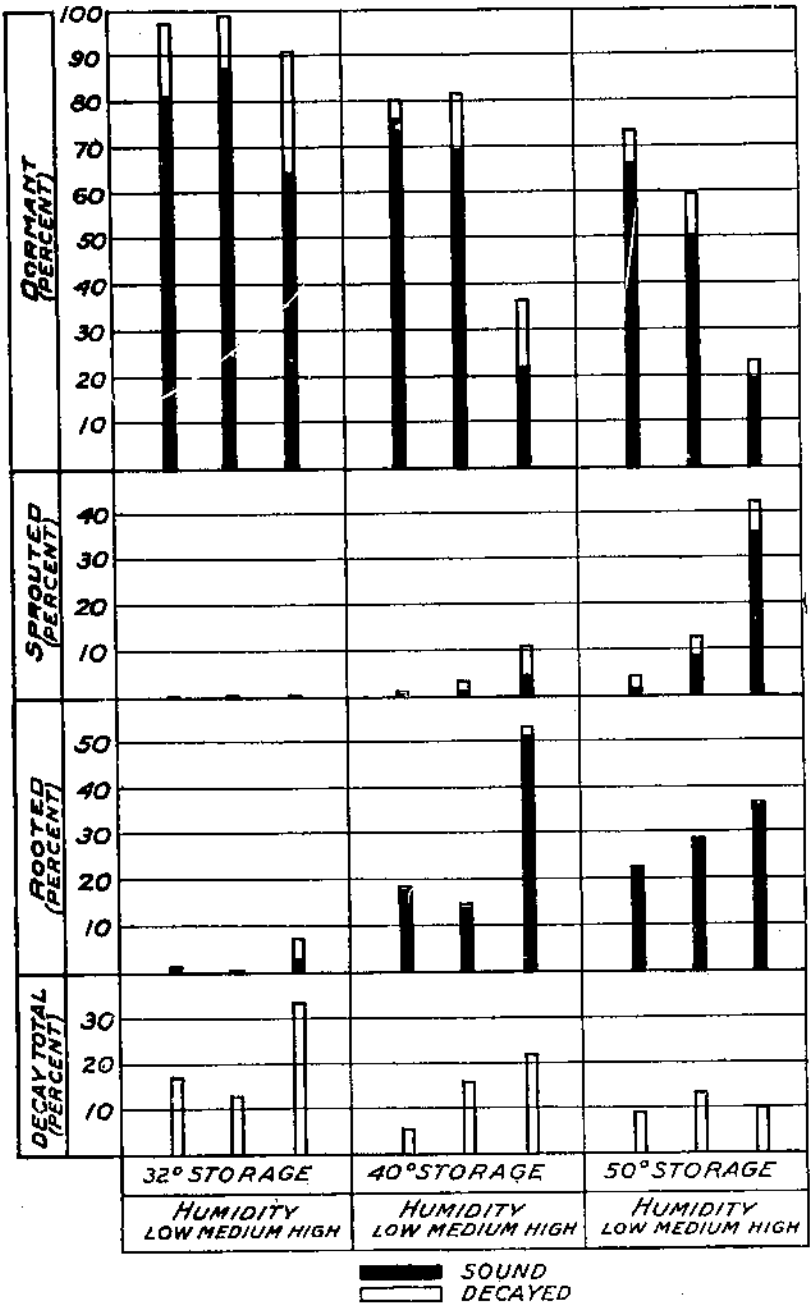

FIGURE 5.—Condition (expressed in percentage) of field-run Yellow Strasburg onion sets after storage at 32°, 40°, and 50° F., with low, medium, and high relative humidities, from October 18, 1928, to March 23, 1929.

On March 23 all the trays were removed from storage and the contents inspected to determine by actual count the number of sets

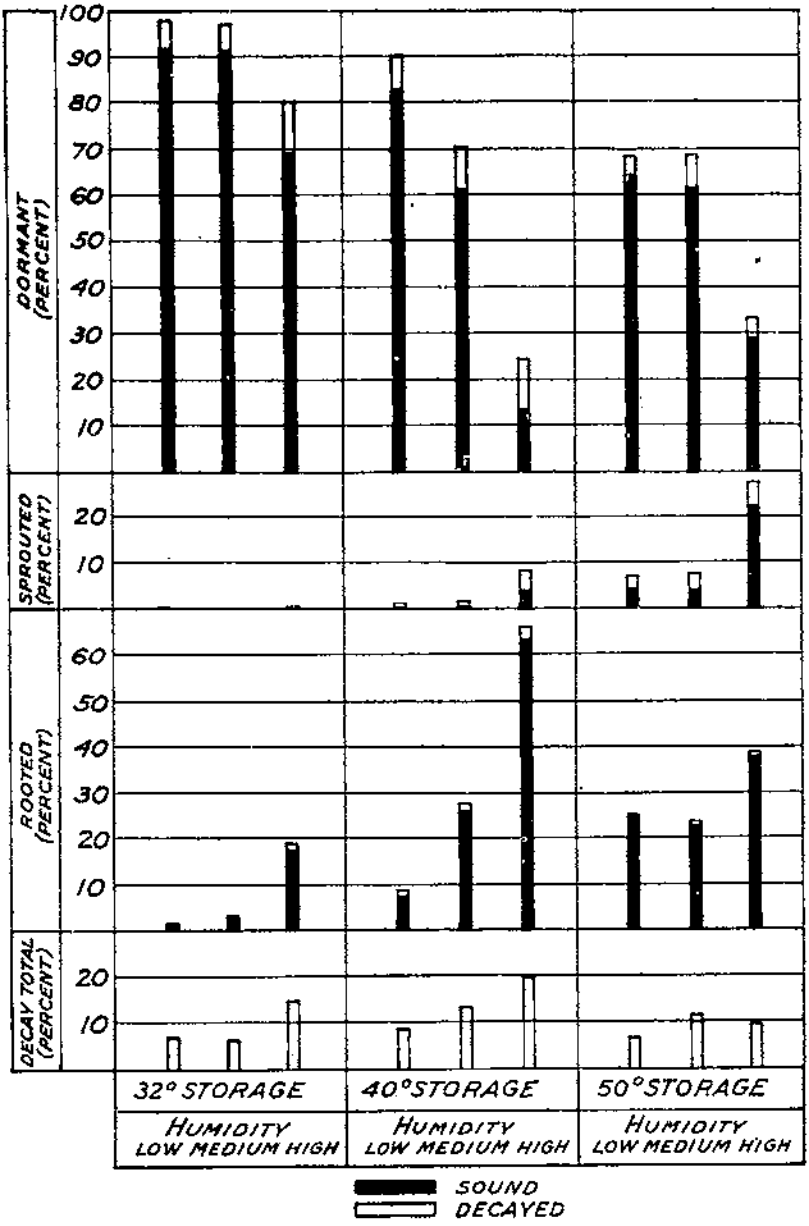

FIGURE 6.—Condition (expressed in percentage) of hand-sorted Yellow Strasburg onion sets after storage at 32°, 40°, and 50° F., with low, medium, and high relative humidities, from October 16, 1928, to March 23, 1929.

remaining dormant and those that were sprouted, rooted, or decayed. The results of the final inspections are shown in figures 5 to 9. When

the hand-sorted and field-run lots are compared, there is apparent a very slight advantage in favor of the hand-sorted lots, accounted

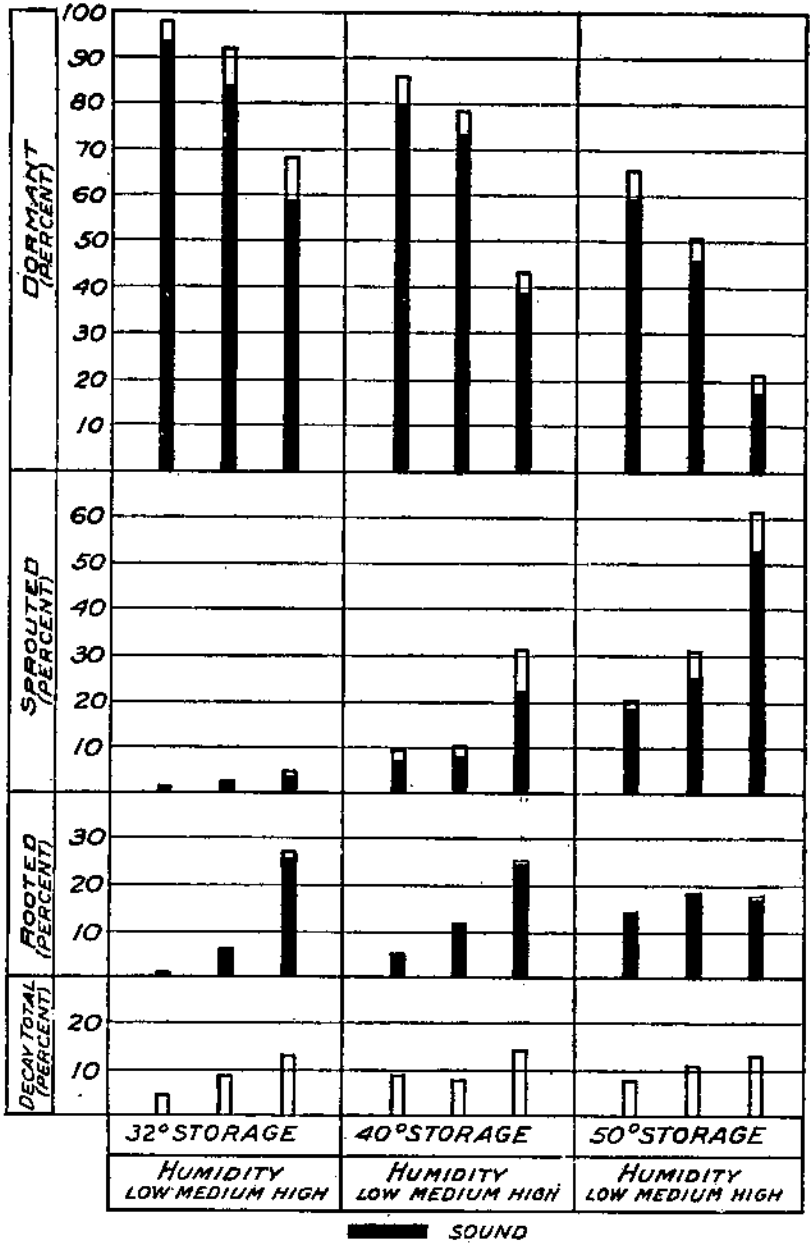

FIGURE 7.—Condition (expressed in percentage) of field-run Red Wethersfield onion sets after storage at 32°, 40°, and 50° F., with low, medium, and high relative humidities, from October 16, 1928, to March 23 1929.

for largely by somewhat less decay. The advantage is less than the figures appear to indicate, since in hand-sorting an average of

about 5 percent of decay was removed before the storage period was begun. Under such conditions it is doubtful if the extra time and

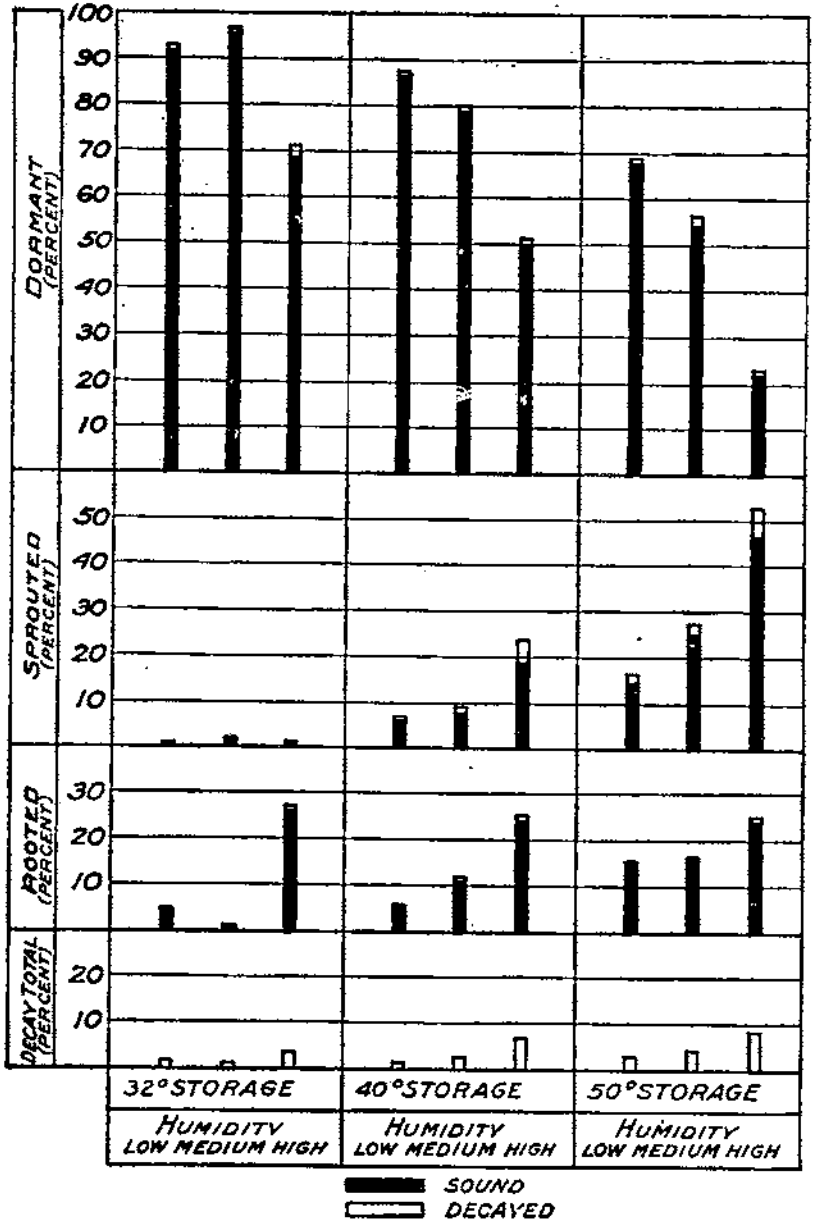

FIGURE 8.—Condition (expressed in percentage) of hand-sorted Red Wethersfield onion sets after storage at 32°, 40°, and 50° F., with low, medium, and high relative humidities, from October 16, 1928, to March 23, 1929.

labor required for this sorting is justified by the results. The somewhat greater loss in weight in the field-run lot was undoubtedly due to the greater amount of gross decay.

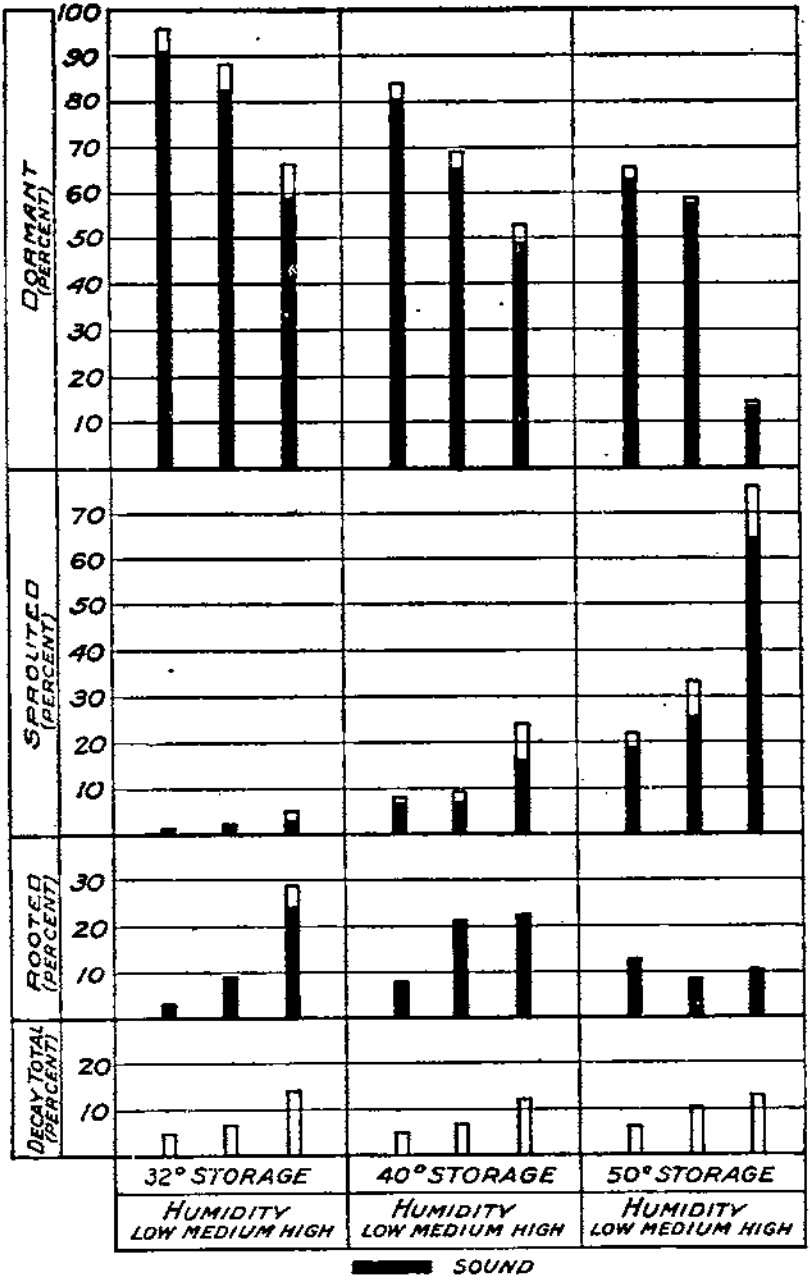

FIGURE 9.—Condition (expressed in percentage) of field-run White Portugal onion sets after storage at 32°, 40°, and 50° F., with low, medium, and high relative humidities, from October 16, 1928, to March 23, 1929.

SEASON OF 1929-30

The sets used during the season of 1929–30 were of the same three varieties as were used the preceding season. They were grown in northern Indiana and represented only field-run lots. After about 6 weeks of the usual field curing, a lot of each variety was expressed to the laboratory at Arlington Experiment Farm, where they arrived November 29. The sets were placed in nine trays for each variety, the contents of each tray weighing about 11 pounds. The trays were stacked in the workroom until December 2, when they were stored in the several chambers already described.

On March 18, at the end of the storage period, the total loss in weight was determined. After being weighed the sets were inspected as usual to determine the number remaining dormant and those that were sprouted, rooted, and decayed. The percentage loss in weight due to the different storage conditions is shown in table 14, while the inspection results are shown in figures 10, 11, and 12.

TABLE 14.—*Percentage loss in weight of yellow, red, and white onion sets after storage from Dec. 2, 1929, to Mar. 18, 1930, at 32°, 40°, and 50° F., with low, medium, and high relative humidities (having saturation deficits of 0.067, 0.037, and 0.016 inch of mercury) at each storage temperature*

Relative humidity	Loss in weight of specified variety after storage at indicated temperature								
	32° F.			40° F.			50° F.		
	Yellow	Red	White	Yellow	Red	White	Yellow	Red	White
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Low	22.2	24.3	26.3	16.7	25.9	19.3	18.3	18.0	17.7
Medium	15.8	17.8	20.0	15.0	13.9	14.8	16.8	16.5	16.4
High	9.5	9.7	10.8	12.1	10.2	13.1	11.4	10.6	14.7

RESULTS

A review of the results of both seasons' work shows the importance of a comparatively low humidity in keeping sets in a sound dormant condition and free from decay or top and root growth. In comparing the results from all the conditions there is shown in general as great differences between those from the different humidities at each temperature as is seen between the same humidities in the different temperatures. In all lots the greatest number of onions remaining sound and dormant was found at 32° F. with low humidity, although at all temperatures there was comparatively little difference in the results from the low and medium humidities. At the high humidities in every temperature there was a marked drop in the number of sets remaining dormant and an increase in sprouted and rooted specimens. Unlike the large onions, the sets showed in general a more or less distinct increase in sprouting, rooting, and decay as the storage temperatures and the humidities increased. In general, the red sets kept slightly better than the other varieties. The decay was practically all neck rot, with a few specimens of slimy soft rot at the high humidities.

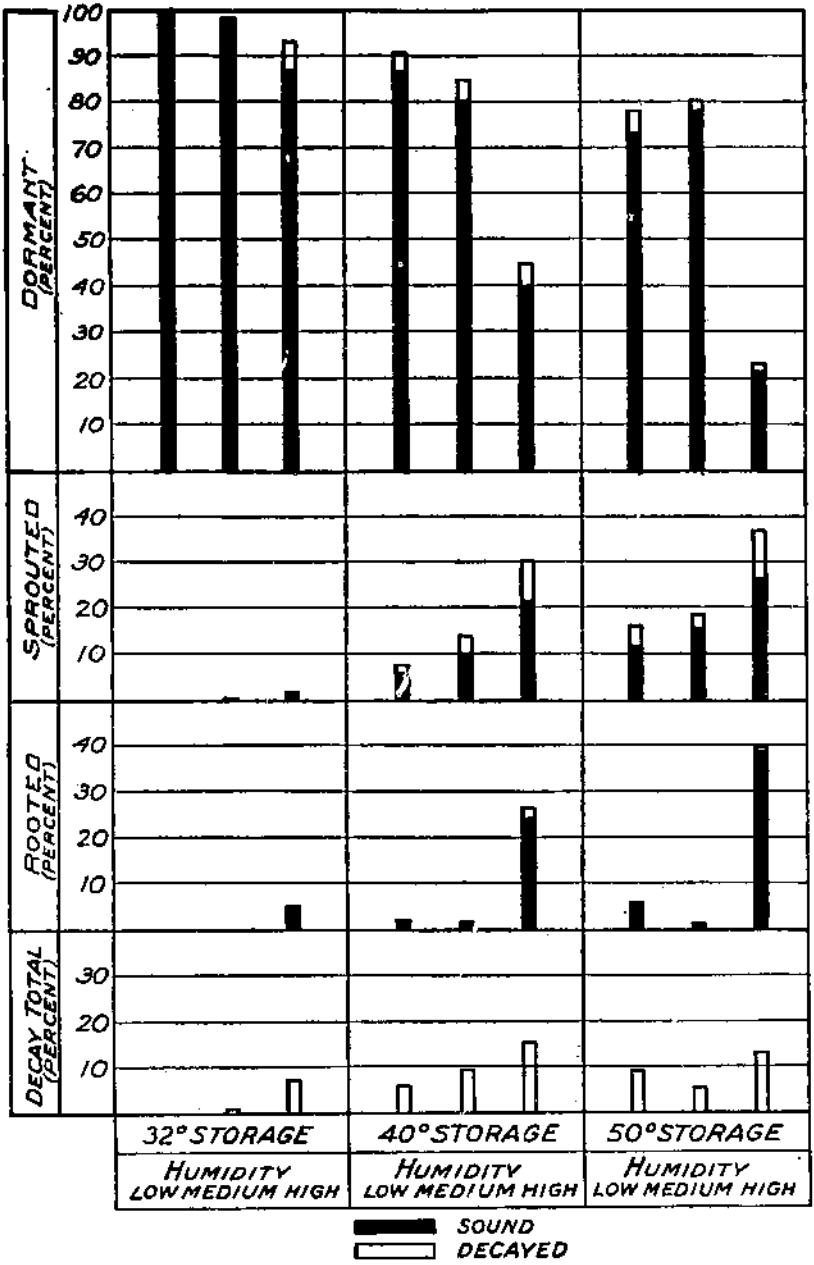

FIGURE 10.—Condition (expressed in percentage) of field-run Yellow Strasburg onion sets after storage at 32°, 40°, and 50° F., with low, medium, and high relative humidities, from December 2, 1929, to March 18, 1930.

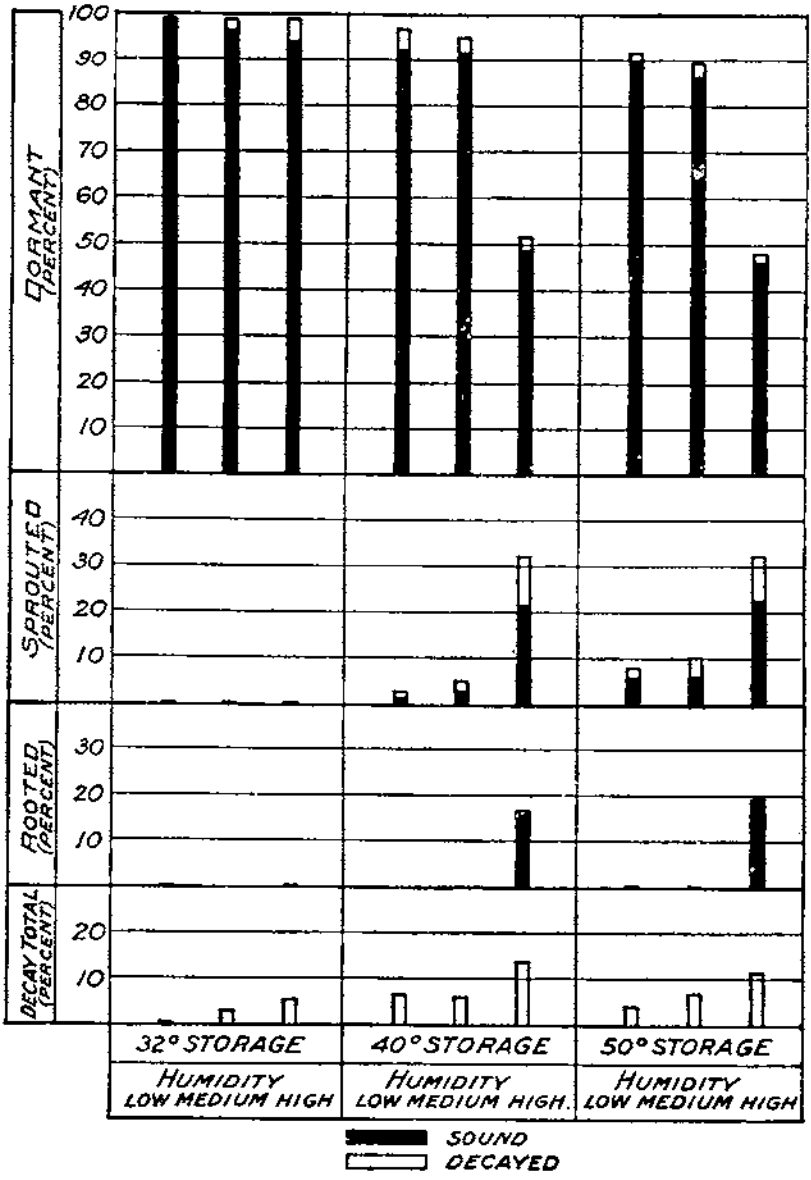

FIGURE 11.—Condition (expressed in percentage) of field-run Red Wethersfield onion sets after storage at 32°, 40°, and 50° F., with low, medium, and high relative humidities, from December 2, 1929, to March 18, 1930

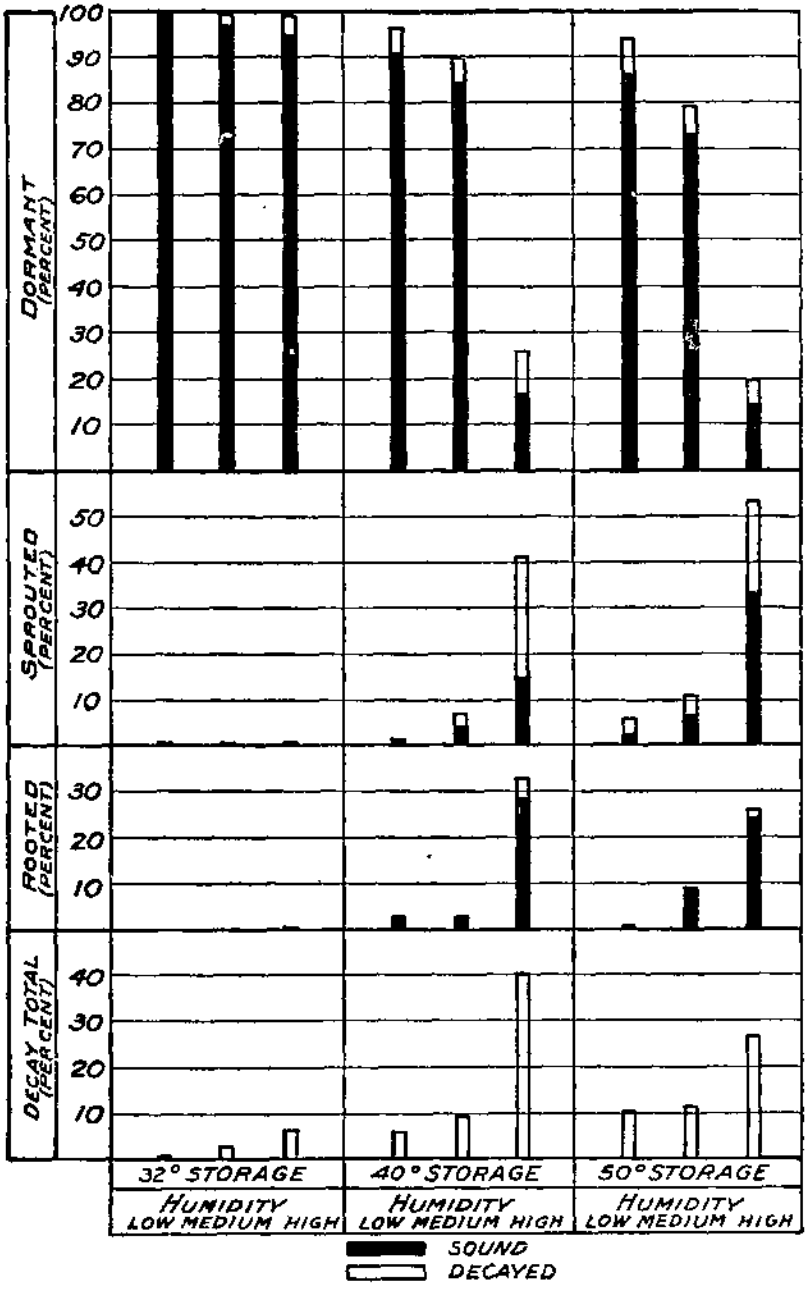

FIGURE 12.—Condition (expressed in percentage) of field-run White Portugal onion sets after storage at 32°, 40°, and 50° F., and low, medium, and high relative humidities from December 2, 1929, to March 18, 1930.

PHYSIOLOGICAL BREAK-DOWN

A condition resembling freezing injury and often diagnosed as such has been repeatedly noted in various lots of onions on the market by both dealers and investigators. However, careful investigation of the history of these lots indicated that the possibility of freezing being the cause of the trouble was very doubtful. This condition has frequently been the basis for damage claims for freezing injury against carriers and storage-house owners. For want of a better term the condition will be referred to as physiological break-down. Like freezing injury, physiological break-down is marked by a grayish water-soaked discoloration in certain scales, usually in those at or near the surface of the onion but may be found in one or more deeper scales. This condition may include only a part of the scale or may extend entirely around the scale affected.

Complaints regarding this condition prompted the writers during field trips in early February, both in 1927 and 1928, to take particular care to investigate onions stored in various localities. At several points in New York, Massachusetts, and Ohio, onions were carefully examined, and the condition was found in several specimens in typical commercial storage houses, the owners of which were positive that the onions had never been frozen. In all cases they had been brought from the fields before freezing weather, and no evidence of freezing injury, usually characterized by localization of the damage near the outside walls of the house or near doors, could be found; instead, the affected bulbs were found scattered throughout the storage houses. In September 1928 several commercial onion-growing centers in Massachusetts; Long Island, New York; Ohio; and Wisconsin were visited and onions in the field were examined; in nearly every case some evidence of physiological break-down was found, although no freezing had taken place. The results from cutting 50 specimens in each lot are as follows:

Lot no.	*Number showing break-down*	Lot no.	*Number showing break-down*
1	9	8	1
2	11	9	3
3	11	10	0
4	10	11	0
5	14	12	7
6	1	13	4
7	6		

Many of the specimens showed only traces of the break-down, and since much of it was in the outer scales it is thought that, after the usual amount of drying out before storing, this condition may disappear. These results are significant in that they prove that a physiological break-down which resembles freezing injury may be found in the field before freezing weather has arrived in onions that are normal in external appearance and that under certain conditions lots containing many such specimens may get into storage. Thus when this condition is discovered it might easily be mistaken for freezing damage. Correspondence with an inspector of food products, working in the Walla Walla section of Washington, revealed the fact that onions in that locality sometimes show this condition in the field.

In order to determine whether storage temperature or humidity influences the development of physiological break-down, samples of

20 specimens from several lots stored in the special chambers already described were cut and examined at the end of the storage period. Representative samples of these lots were examined before going into storage, and the break-down, although very limited in extent, was found in about 2 percent of the onions. The results of these inspections are shown in table 15. The only significance apparent in these results is a tendency toward an increase in break-down in storage at the higher humidities at 40° and 50° F.

From 12 commercial bag lots of Yellow Globe onions stored at 32° F. with both low and high humidities, 50 specimens were cut open and examined at the end of the storage period. No examinations of these onions were made before they went into storage, but all were from the general lot which had been thoroughly mixed and apportioned into 100-pound lots before being stored under the two humidity conditions. The results showed a distinctly greater amount of break-down at the higher humidity (4.7 percent) than at the lower humidity (2.3 percent), although none of this deterioration was at all serious. In most cases it was represented by a very limited amount of watery discoloration in the outer scale only.

TABLE 15.—*Physiological break-down found after approximately 8-months' storage in sample lots of 20 onions each held at three temperatures and humidities*

Storage temperature	Relative humidity	Number of specimens of indicated variety showing break-down									
		Yellow Globe						White Globe			Walla Walla Valencia
		Lot 1	Lot 2	Lot 3	Lot 4	Lot 5	Total	Lot 1	Lot 2	Total	Lot 1
32	Low	1	1	2	1	0	5	0	0	0	2
	Medium	4	0	2	0	0	6	2	1	3	4
	High	1	0	0	1	2	4	0	0	0	1
40	Low	0	0	0	1	0	1	0	0	0	0
	Medium	2	0	1	0	0	3	1	0	1	0
	High	3	0	0	1	7	11	1	0	1	0
50	Low	0	2	0	1	1	4	0	1	1	0
	Medium	3	0	0	5	0	8	1	3	4	0
	High	1	2	2	2	2	9	2	0	2	2

The conclusion to be drawn from the investigations of break-down is that a condition resembling freezing injury sometimes occurs in onions as they come from the field and that it may develop further under certain storage conditions. The presence of break-down greatly complicates the identification of true freezing injury that has occurred either in the field, in transit, or in storage. A complete history of any given lot of onions is obviously required before a satisfactory conclusion can be drawn regarding the cause of the trouble.

SUMMARY

In order to study the influence of different temperature and humidity conditions on keeping quality, onions and onion sets of several varieties were stored for various periods at temperatures of 32°, 40°, and 50° F., with low, medium, and high humidities at each temperature.

Periodic inspections were made, and all specimens showing sprouting or top growth, rooting, and decay were recorded and discarded.

In general, the amount of sprouting in stored onions was influenced little by the humidity, but increased with an increase in the temperature, whereas rooting increased with humidity and was little influenced by temperature. The amount of decay appeared to show only a general slight tendency to increase as both temperatures and humidities increased, but this was not marked. Most of the decay was identified as neck rot.

Onion sets showed an increase in sprouting, rooting, and decay as the storage temperatures increased and as humidities increased at each storage temperature.

For keeping both onions and onion sets in a sound dormant state the best storage conditions were found to be 32° F. and a low relative humidity of about 64 percent.

A condition, having symptoms which were apparently the same as those resulting from freezing injury, was found in onions both in storage and in the field before freezing had occurred. This condition, referred to as physiological break-down, is sometimes found in stored commercial lots of onions. It is often confused with freezing injury and has been the cause of legal action against carriers and storage-house operators. In control lots put up in 100-pound bags and stored at 32° F. at both low and high humidities, the number of specimens showing break-down at the high humidity was greater than the number of specimens showing break-down at the low humidity. Aside from this, no new information was obtained on the control of this trouble.

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