The Development of Rice Grains under Controlled Environment II. The Effects of Temperature Combined with Air-Humidity and Light Intensity During Ripening on Grain Development

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The Development of Rice Grains under Controlled Environment

II. The Effects of Temperature Combined with Air-Humidity and Light Intensity During Ripening on Grain Development

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Summary

Using the same varieties and the same phytotrons used in the previous work, the combined effects of temperatures with different light intensity and air-humidity on ripening were studied. The rate of ripening progressively increased as the temperature increased, being highest at 35/30° where ripening almost ceased at the 2nd to 3rd week after fertilization. In reverse proportion to the rate, the final kernel weight was progressively greater as the temperature declined, slowing the ripening rate.

At higher temperatures, a low air-humidity was more favorable for ripening, but at lower temperatures the humidity had little effect. Low light-intensity markedly depressed ripening with less production and translocation of photosynthate to grains and caused a higher percentage of nitrogen in both grains and straw. In the limits of this experiment, the nitrogen absorption was not significantly influenced by the treatments, but the TAC accumulation was progressively greater as temperature decreased, as air-humidity decreased with higher temperatures, and as light-intensity increased with all temperatures.

With scantiness of assimilates at higher temperatures, the early flowered grains preferentially deprived of them, thus making much variation in weight among grains. Usually the kernel weight was higher in the grains located in the upper part of a panicle and at locations 1, 5, 4, and 1' of each primary and secondary branch, respectively.

Under lower temperatures, a longer period of photosynthesis with a lower rate of respiration accompanied with gradual translocation of assimilates to grains may have caused the high accumulation of TAC in shoots and produced grains of relatively uniform weight, due to a decreased competition among them for assimilates.

There was a strong correlation between grain DW/straw DW and grain N content/straw N content, suggesting a parallel translocation of nitrogen and carbohydrate to grains. However it is clear that at higher temperatures relatively less, and at lower temperatures relatively more TAC accumulated in grains, making the nitrogen percentage of both grains and straw higher at the former and lower at the latter.

As far as the final kernel weight is concerned, IR–8 seemed to be more tolerant of higher temperatures as compared with Norin–17. In this experiment, too, the optimum temperature for ripening, as far as the final ripening index is concerned, was 20/15° C (daily mean of 17.5°C) for both varieties, which is lower than ever reported before.

Matsushima and Manaka (1) reported that the weak light at higher temperatures was unfavorable for grain development. In this study a similar experiment to test the combined effects of temperature with light intensity and air-humidity during the ripening period was conducted. However, the author used wider day temperature limits including the highest 35°C with each 5°C decrease of night temperature, which may be more like natural temperature conditions occurring not only in temperate but also in tropical regions, to compare the responses to these conditions between a Japanese rice and a tropical rice.

Materials and Methods

Varieties used and their growing methods were the same as in the previous work (3). Three sets of cabinets were prepared under natural day-light, each set consisted of 4 temperature rooms; day temperature of 20, 25, 30 and 35°C, for each decrease of 5°C in night temperature. Daytime was from 6 am to 6 pm and during the remaining 12 hrs all sets were covered each by a dome of sheet irons to keep them completely dark. One of three sets was used for light intensity test, a half of each room being supplemented with a 5000 f.c. special lamp (Yoko-lamp, Toshiba Electric Co.) during daytime (S.L plot) and the other half being covered by a vinyl blind to cut sun light at about one third intensity (W.L plot). The air humidity of each room was held at about 60 to 70 per cent R.H. The other two sets were used for air-humidity trial, the one set with 70 to 80 percent R.H. (H.H. plot) and the other with 50 to 60 percent R.H. (L.H. plot). Moisture was increased by mixing water vapor with the in-going cool air stream.

Flowers which opened on the same day were marked with enamels, and one or one and a half days after that the plants were moved to the rooms for treatment. This was August 14, 1968. During the ripening period, several culms each with about 30 marked grains were cut at their base at one week intervals for estimating the trend of 1000-kernel-weight, panicle/straw ratio and for chemical analysis; i.e. nitrogen by semi-micro Kijeldahl method, total sugar and crude starch by Murayama's method (2).

Results and Discussion

Fig. 1 shows the trend of panicle/straw ratio by dry weight on the left and of 1000-kernel-weight on the right. 1000-kernel-weight one week after fertilization was proportionately greater under higher temperatures, being about 8 grams at 35/30°C combined with low air-humidity or with strong light-intensity, but about

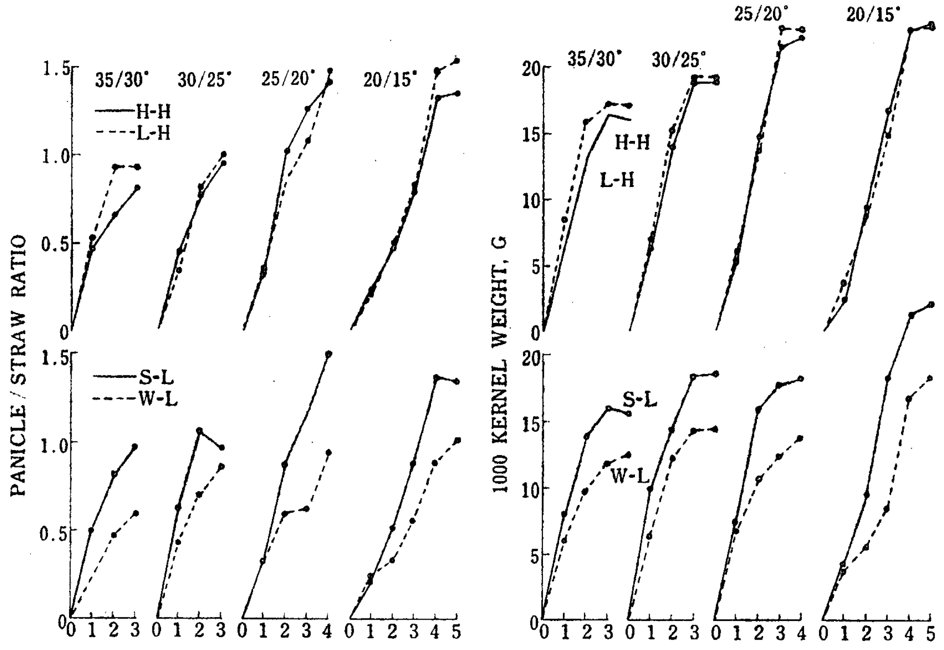

FIG. 1 Trend of panicle/straw ratio and of 1000–kernel–weight during ripening period as affected by temperature, air-humidity and light intensity (Norin–17) H-H; high humidity, L-H; low humidity, S-L; strong light W-L; weak light

half at 25/20°C. A week later, the kernel weight of rice at 35/30°C reached about 16 grams, which is less than that of 30/25 or 25/20°C. At this time the ripening almost ceased accompanied with the yellowing of the grain hulls at 35/30°C, but it continued to progress for a longer period as temperature decreased, resulting in a higher final kernel-weight. Air-humidty had little effect on the ripening except at 35/30°C where a lower humidity was more favorable. In contrast, light-intensity influenced it significantly by causing a higher rate of ripening and a greater grain weight under high light intensity.

The panicle/straw ratio followed almost the same trend as kernel weight suggesting that the main factor affecting the ratio was the degree of translocation of assimilates to the panicle.

The senescence of leaves during ripening is shown in Fig. 2. In the air-humidity trial, the senescence was progressively hastened as air-temperature increased until the 2nd week after fertilization concomitant with the increased rate of ripening. Thereafter, however, it was more rapid at 30/25 and 25/20°C, and in the 4th week the number of green leaves was more at 35/30°C than at 30/25 or 25/20°C. Thus, the green leaf number at each maturity date was greatest at 35/30°C and was followed by 30/25, 25/20 and 20/15°C. A similar trend was observed in the light-intensity trial during the early ripening period, but at later periods no such clear tendency was found as in the humidity trial. The cause of this discrepancy is not understood. In general, low air-humidity and high light-intensity both hastened senescence of leaves except at 20/15°C.

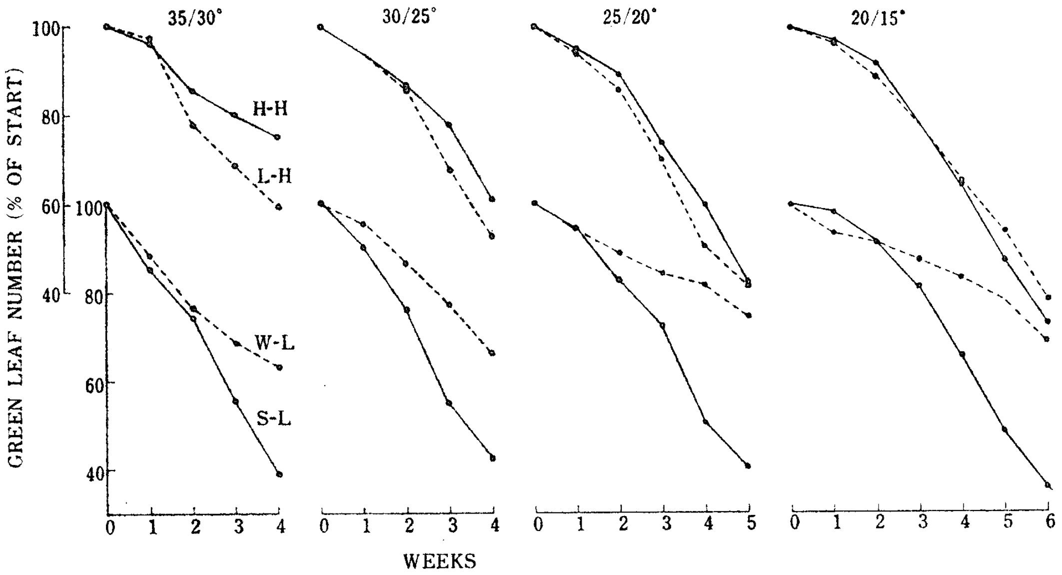

FIG. 2. Trend of green leaf number during ripening period as affected by temperature, air-humidity and light intensity (Norin-15)

The relations between temperature and the trend of 1000-kernel-weight and panicle/ straw ratio are shown in Fig. 3, both being expressed as the mean of each of 4 treatments (H-H, L-H, S-L, W-L). It may be clear that the rate of ripening progressively increased but the ripening itself ceased earlier, as the temperature increased, resulting in a lower kernel weight and panicle/straw ratio. These results coincided well with the previous work (3).

Fig. 4 shows the variability of weight among grains of different locations in a panicle influenced by the 4 treatments. In general, low humidity and strong light promoted grain weight, and the grains at location 1, 4, and 5 were heavier, the grains at location 2 the lightest. Grain 4 or 5 were often superior to grain 1 in weight. At the secondary branches grain 1' was the heaviest and 2' the lightest.

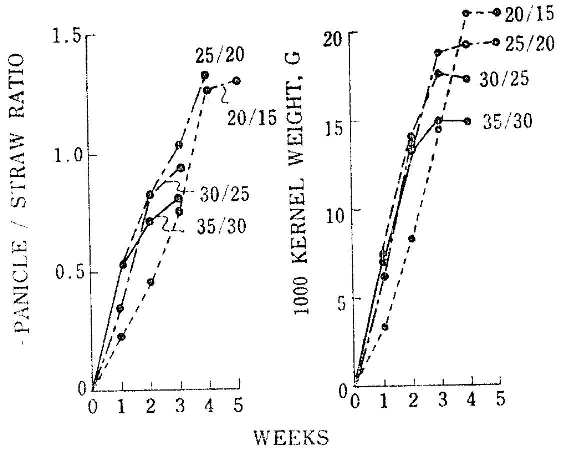

FIG. 3. Trend of panicle/straw ratio and 1000-kernel-weight as affected by temperature. Means of each 4 treatments (Norin-17)

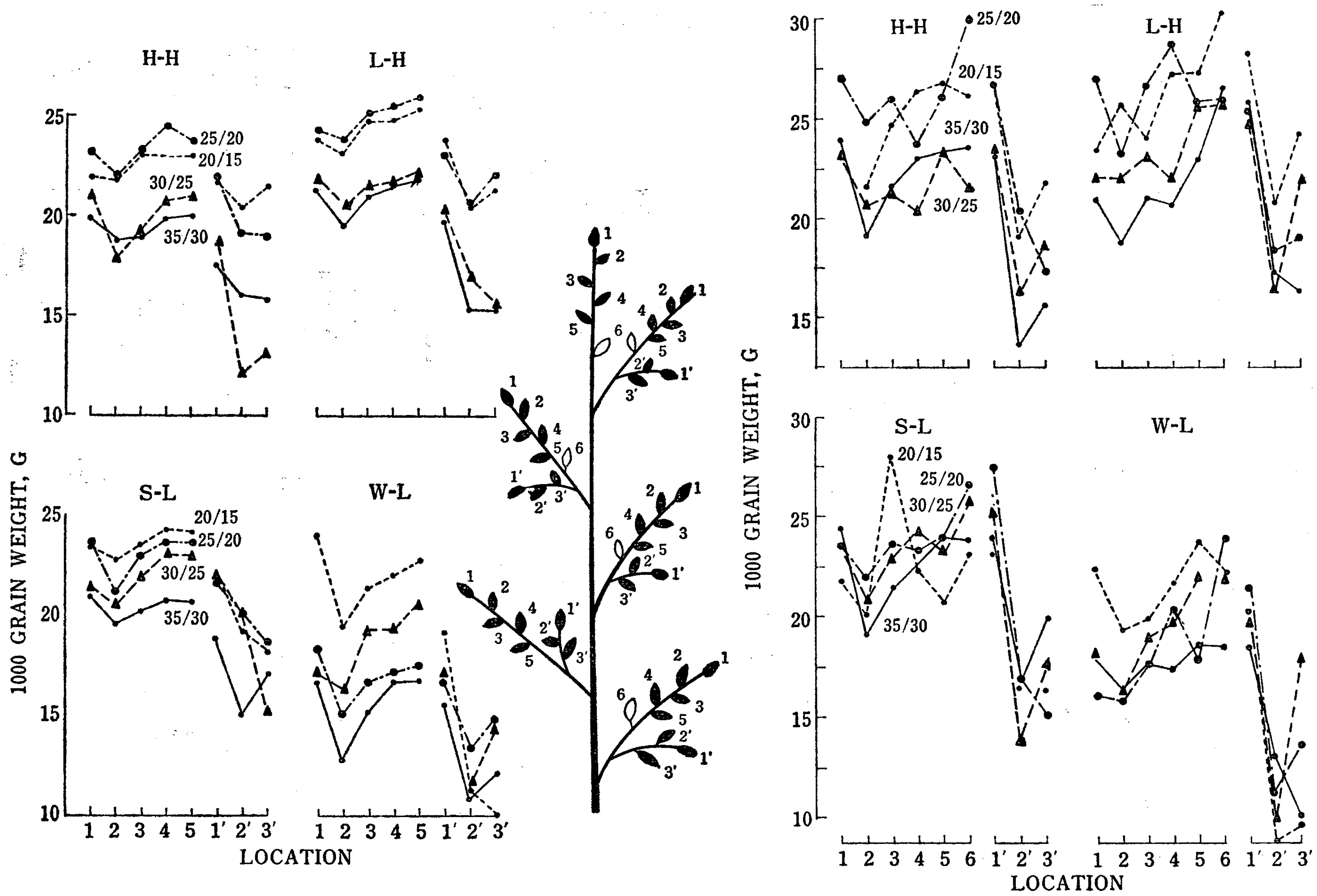

FIG. 4. 1000-grain-weight at different location on primary and secondary branches as affected by temperature, air-humidity and light intensity (Norin-17: left, IR-8: right)

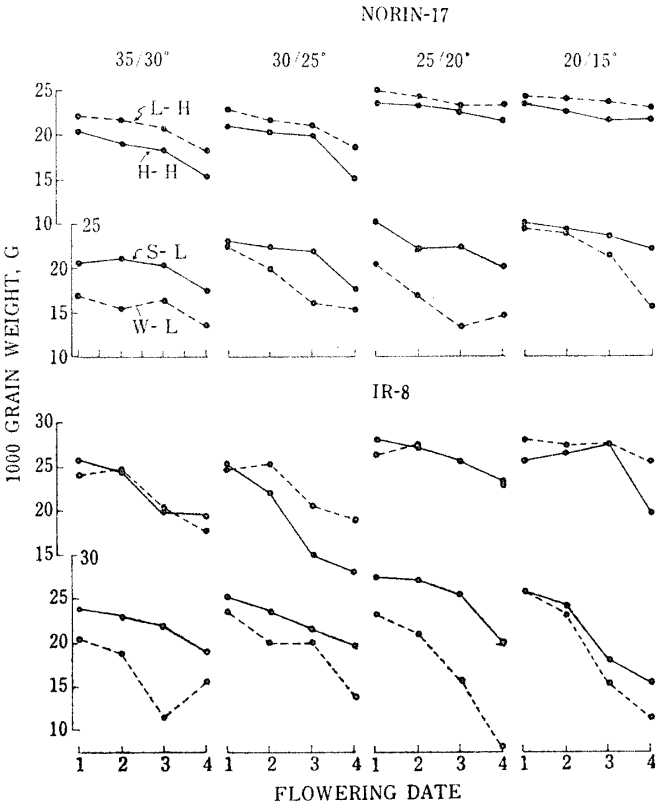

FIG. 5. 1000-kernel-weight as affected by flowering order, temperature, air-humidity and light intensity.

The variation of grain weight due to earliness of flowering date is shown in Fig. 5. In this case, the enamel colors for marking opened flowers were according to the opening day. Treatments were started after the fertilization of all flowers of each panicle was finished. It is clearly demonstrated that kernel weight was greater with the earliness of flowering, with the decrease of temperature or humidity and with the increase of light-intensity. Generally, grain 1 flowered first, being followed in order by 5, 4, 3, and 2 (Fig. 4). Considering the results of Fig. 4 and 5, it may be concluded that the earlier flowering grains reached a greater final grain weight. At higher temperatures the grain weight was markedly variable among locations, suggesting an existence of a great competition for assimilates which are insufficient under those conditions. (4)

Fig. 6 shows the trend of nitrogen and TAC concentration in grain and straw during the ripening period. The nitrogen concentration was little affected by air-humidity although a little higher under high humidity. In contrast, light-intensity affected it greatly being always higher under weak light conditions. Temperature also significantly affected the nitrogen concentration; under higher temperatures it increased or decreased more rapidly in the straw or in the grains, respectively, as compared with that under lower temperatures. It is noted that the grains under higher temperatures increased in nitrogen concentration as

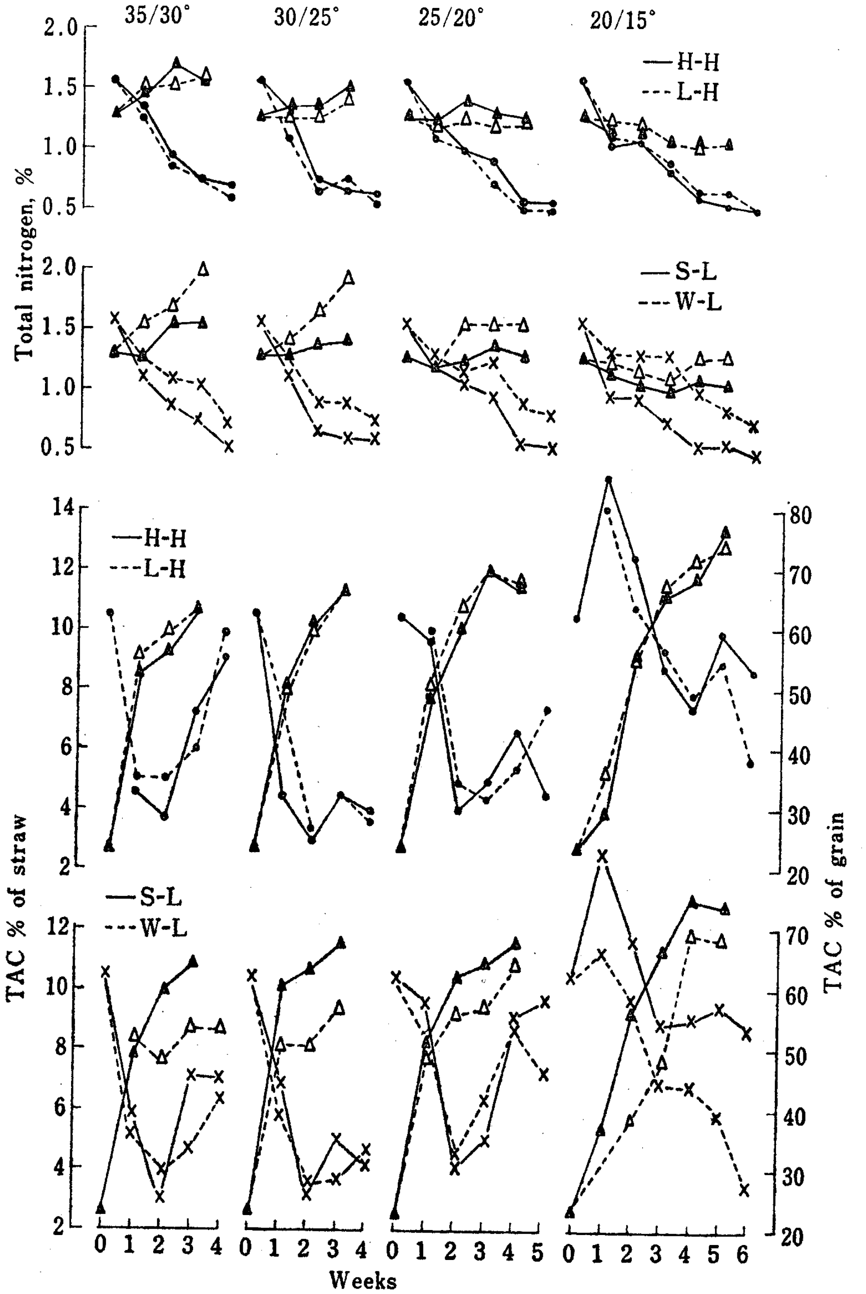

FIG. 6. Trend of total nitrogen and total available carbohydrate concentrations during ripening period in the grains and straw as affected by temperature, air-humidity and light intensity (Norin-17) ▲△ Grains ●× Straw

maturation advanced, but under lower temperatures the concentration was almost constant or even gradually decreased at 20/15°C. These results may be ascribed to the differential TAC accumulation in the grains, showing a smaller amount in the former and greater in the latter.

TAC concentration of straw, on the other hand, decreased more rapidly at higher temperatures. At 35/30°C, it dropped to the lowest level at the 2nd week and then increased again to a higher level than at 30/25°C. This recovery of TAC

TABLE 1. *Dry Weight, Nitrogen and TAC Content of Each Culm (Panicle and Straw) and Humidity and*

Variety			Norin-17		
Temperature, °C Day/Night	Humidity Light	DW* per Culm, g	$\frac{G^{**}(DW)}{S^{**}(DW)}$	Nitrogen per Culm,mg	$\frac{G^{**}(N)}{S^{**}(N)}$
35/30	H.H	2.87	0.74	36.8	1.08
	L.H	3.41	0.82	42.5	1.38
	S.L	3,32	0.75	40.0	1.24
	W.L	2.57	0.64	37.7	1.18
	Mean	3.04	0.74	39.3	1.22
30/25	H.H	2.99	0.99	37.3	1.68
	L.H	3.35	1.04	38.1	1.76
	S.L	3.19	1.15	36.9	2.00
	W.L	2.65	0.77	37.5	1.50
	Mean	3.05	0.99	37.5	1.74
25/20	H.H	3.65	1.25	37.3	2.07
	L.H	3.49	1.32	35.6	2.08
	S.L	3.67	1.09	38.2	1.86
	W.L	2.76	0.81	37.6	1.08
	Mean	3.39	1.12	37.2	1.77
20/15	H.H	3.66	1.14	32.6	1.93
	L.H	3.37	1.31	31.0	2.17
	S.L	3.28	1.20	32.0	1.57
	W.L	2.93	1.00	33.3	1.48
	Mean	3.31	1.16	32.2	1.79

* Straw plus panicle **G: Grain, S: Straw *** Arbitrary designated by the author unknown physiological disease

concentration at 35/30°C agreeded with the cease of ripening, being accompanied with the devlopment of new tillers from higher nodes. A similar phenomenon was mentioned in the previous work. In contrast, at 20/15°C, the concentration increased at an earlier period, then declined gradually to a rather high level at maturity except under weak-light conditions, where it remained at the lowest level. The TAC concentration of grains changed almost parallel to the trend of kernel weight and reached the higher level as the temperature declined. Air-humidity affected little on TAC concentration, but strong light markedly increased it.

Fig. 7 shows the mean nitrogen and TAC content per culm (straw plus grains) at respective maturity dates. The total nitrogen absorption was highest at 35/30°C regardless of possible earlier senescence of roots, but its content in grains was relatively small with much nitrogen retained in the straw (Table 1). This much nitrogen absorption may be attributed to the new roots which emerged from the new tillers during maturation. The decreased translocation of nitrogen to grains seemed to be caused by their early termination of acceptance of assimilates under

Their Grain/Straw Ratios at Each Maturity Date, as Influenced by Air-Temperature, Air-Light Intensity

				IR-8	
TAC per Culm, mg	G**(TAC) / S**(TAC)	1000-Kernel Weight, g	R.I***	1000-Kernel Weight, g	R.I***
781	5.1	15.4	1687	18.1	1390
979	5.3	16.2	1940	19.0	1459
923	6.9	15.6	1895	18.0	1382
535	5.2	12.6	1630	14.1	1107
948	5.6	15.0	1788	17.3	1335
1057	16.9	16.3	1750	17.3	1571
1207	18.8	18.0	2088	18.6	1434
1223	18.1	18.6	2129	18.9	1603
730	9.6	14.4	1355	14.6	1213
1054	15.9	16.8	1831	17.4	1455
1550	13.2	20.2	2252	22.1	1991
1496	17.0	20.7	2388	20.1	1992
1472	8.0	18.3 ?	2087 ?	21.4	2002
926	6.0	13.8	1480	16.5	1127
1361	11.1	18.3	2052	20.0	1779
1673	8.8	21.8	2532	21.0	2029
1553	10.9	21.6	2484	22.1	2085
1443	10.5	21.1	2418	19.1	1573
1086	11.6	17.7	1858	15.4	1616
1439	10.5	20.6	2323	19.4	1826

indicating (fruiting percentage (%) ×1000-kernel-weight (g)) ? Low value due to

high temperature. At both 30/25 and 25/20°C, much nitrogen moved to the grains, although total nitrogen absorption was less than at 35/30°C. In contrast, at 20/15°C, absorption itself was depressed but the absorbed nitrogen moved mostly to the grains. Under higher temperatures, low air-humidity seemed to encourage the absorption, but not so under lower temperatures. Weak light diminished the rate of distribution of absorbed nitrgen to grains. (Fig. 7, Table 1).

On the contrary, the TAC accumulation per culm, increased as the temperature decreased (Fig. 7, Table 1). At lower temperatures, assimilates seemed to move into the grains continuously for longer periods with less respiration loss, although with a slower rate of translocation and lower rate of photosynthesis (5), as contrasted with that at higher temperatures where translocation to grains was rapid though inhibited earlier. Thus the grains matured earlier accompanied with much respiration loss.

It is considered that such high temperatures as 35/30° during the ripening period hastened translocation of assimilates to grains, caused early cease of

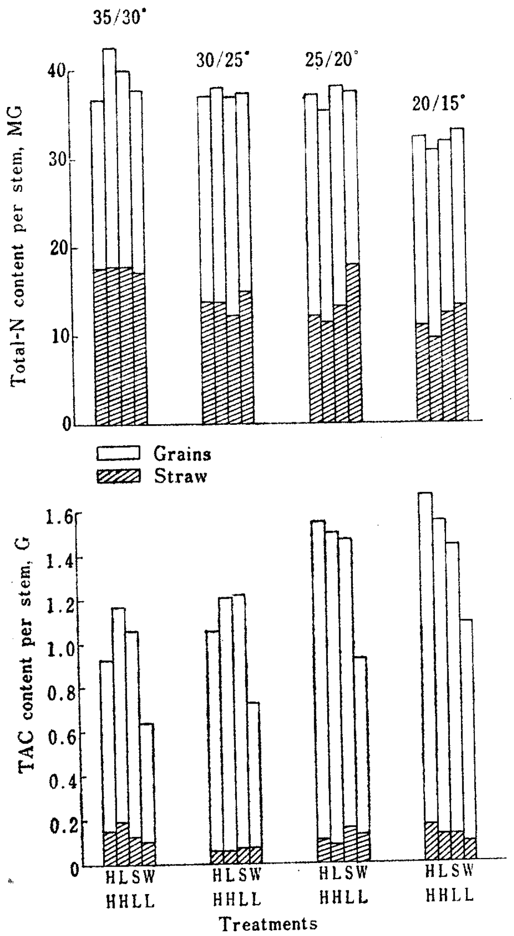

FIG. 7. Total nitrogen and TAC (total sugar+crude starch) accumulation in every culm (grains+straw) at each maturity date as affected by temperature, air-humidity and light intensity.

ripening and eventually brought a low ripening index as shown in Table 1. This low value is mainly attributed to the low 1000-kernel-weight. Early grain maturation resulted in relatively high retainment of nitrogen and carbohydrate in the straw expressed by low grain N/straw N and grain TAC/straw TAC ratios (Table 1). At 30/25°C, the rate of ripening was as high as at 35/30°C, but the 1000-kernel-weight was higher than the latter resulting from longer ripening periods and more efficient translocation of assimilates to grains with the highest grain TAC/straw TAC ratio, although its ripening index was lower than those of lower temperatures probably because of shorter ripening period and much respiration loss. As the temperature declines, the rate of ripening decreases, but the grains remain green for longer period permitting accumulation of more photosynthates with less respiration loss, thus resulting in a greater 1000-kernel-weight at maturity. Thus at 20/15°C the greatest ripening index was obtained (Table 1).

IR-8 behaved almost like Norin-17 in response to temperature levels, air-humidity and light intensity. However, as far as 1000-kernel-weight is concerned,

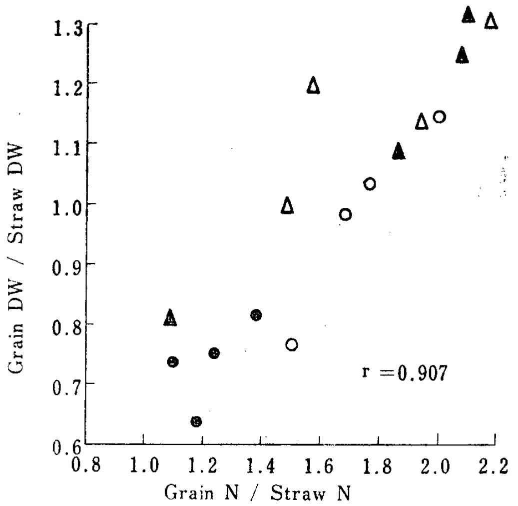

FIG. 8. The correlation between grain DW/straw DW and grain N/straw N (Norin-17)

IR-8 seems to be more resistant to higher temperatures and more sensitive to low temperatures as contrasted with Norin-17 (Table 1). The above-mentioned results perfectly coincided with the previous work (3).

It is an interesting fact, as shown in Fig. 8, that the nitrogen and dry matter distribution between grains and straw exactly correlates. This may indicate an accompanied translocation of carbohydrates and nitrogen to grains, as generally accepted, although the translocation rates of the two materials were somewhat differentially influenced by temperature and light intensity (Fig. 6).

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