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Murata, Satoshi
Laboratory of Agricultural Process Engineering, Faculty of Agriculture, Kyushu University

Miyauchi, Kiyoshi
Laboratory of Agricultural Process Engineering, Faculty of Agriculture, Kyushu University

Wang, Yanyao
Laboratory of Agricultural Process Engineering, Faculty of Agriculture, Kyushu University

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Respiration Rate of Thirteen Kinds of Japanese Fresh Vegetables

Satoshi Murata, Kiyoshi Miyauchi and Yanyao Wang

Laboratory of Agricultural Process Engineering, Faculty of Agriculture,
Kyushu University 46 -05, Fukuoka 812, Japan

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The respiration rate of fresh vegetables has the fundamental significance in storage, but there is few data available on respiration under wide range of temperature. In this study, the relationship between respiration rate and temperature of thirteen kinds of Japanese vegetables were measured by modern precise ventilatory method. Because of respiration being a result of chemical reaction, the relationships between respiration rate and temperature were fitted to Arrhenius' equation and Gore's equation (Modified Arrhenius' equation). The heat of respiration in kJ per ton per day was obtained multiplying the respiration rate of milligrams of CO_2 per kilogram per hour by a factor of 10.61. The heats of respiration were all a little higher than the conventional values.

INTRODUCTION

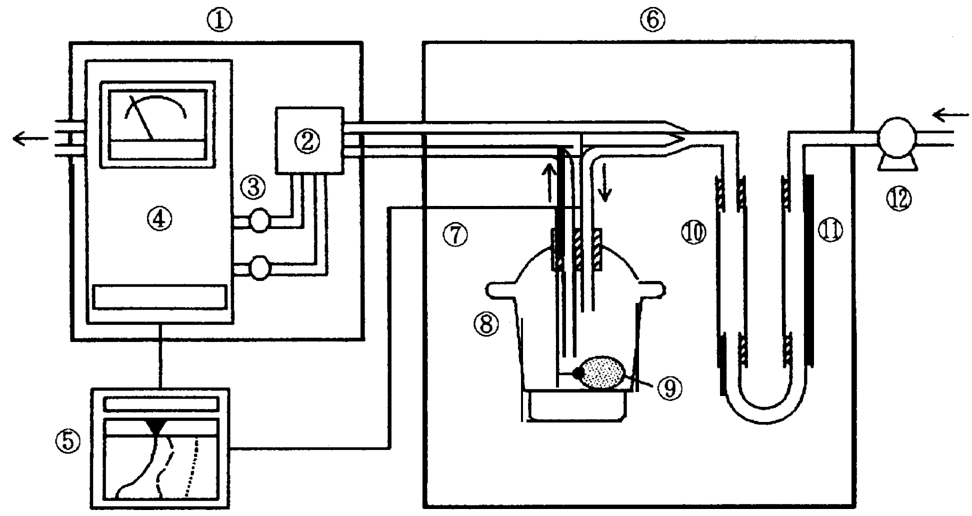
The quality maintenance of fresh vegetables has the significance in storage. In fresh vegetables the consumption reserves of living cells for respiration to produce energy leads to decline the quality of the product. In addition, the generation of heat accompanying the respiration process affects the storage conditions. So it is very important to investigate the characteristics of respiration under various conditions, for quality maintenance of fresh vegetables in storages. Though there are a lot of data on respiration under various local conditions (Honda and Ishiguro, 1967), the respiration data under wide range of temperature is not available presently (specially of Japanese vegetables). In this study the relationship between respiration rate and temperature of wide range for thirteen kinds of Japanese vegetables were measured by modern precise ventilatory method.

Respiration is a typical biochemical reaction in plants. In this process plants get energy' by sugar, acid and fat decomposition. The temperature dependence of biochemical reaction rate is ruled by the Arrhenius' equation just like other general chemical reactions (Sutcliffe, 1981). Also Gore's equation is celebrated as a equation of relationship between respiration rate and temperature. In this paper, measured results were analyzed by both equations and calculated the temperature coefficients. It is expected that the data of this study will contribute to the fundamental data for designing a rational storage equipment, estimation of quality of vegetables in storage and for storage physiology studies.

APPARATUS AND PROCEDURE

1. Measurement apparatus

The apparatus used for measurement is shown in Fig. 1. Samples were placed in a



① CO_2 conc. analyze system ② Electronic cooler
③ Air pump (Small) ④ Infrared gas analyzer
⑤ Recorder ⑥ Controlled temperature box
⑦ c-c thermo-couples ⑧ Desiccator
⑨ Sample ⑩ Silica-gel
⑪ Soda lime ⑫ Air pump

Fig. 1. Schematic diagram of measurement apparatus.

desiccator in the controlled temperature box.

Fresh air was pumped to the controlled temperature box through a plastic tube and then the air was passed over silica gel to dehumidified the flow. In the next step flow of air was passed over the soda lime to reduce the CO_2 content. Then the flow was separated into the sample desiccator and bypass. Then the air in these two pathways were separately dehumidified by using electronic cooler and the dirt and dust were removed by passing through a membrane filter, then passed through a flow meter via a needle valve and an air-pump. Then these two air flows were fed to the infrared gas analyzer with a constant rate (Shimadzu Co, 1988a).

This equipment has two cells and detects the concentration difference of CO_2 in these two air flows (Shimadzu Co, 1988b).

The temperature of the surface of the sample, and the dry and wet bulb temperatures of the desiccator were measured by using c-c thermocouples.

2. Respiration rate

Thirteen kinds of Japanese vegetables were used in this study (Table 1). For the temperature range of 0 ℃ to 25 ℃, the difference of CO_2 concentrations in ppm were measured. Respiration rates of milligrams of CO_2 per kilogram per hour were calculated by using the following equation.

Table 1. Materials.

Materials	Variety	Producing area	Date of hervest
Spinach	Atlas	Kanetake Nishi-ku, Fukuoka	'91.11.24
Coronarium	Chuba	Sue Kasuya, Fukuoka	'91.12.25
Chinese cabbage	Sin Risoh	Hita, Ohita	'92. 1.04
Lettuce (Head)	Top Mark	Tachiarai Mii, Fukuoka	'92. 1.15
Asparagus	Welcome	Saga, Saga Pref	'92. 1.22
Onion	Momiji II	Marugame, Kagawa	'91. 6.
Carrot (topped)	Kuroda Gosun	Isahaya, Nagasaki	'91.12.16
Turnip (topped)	Taibyohikari	Kanetake Nishi-ku, Fukuoka	'91.12.15
Potato	May Queen	Memuro Kawanishi, Hokkaido	'91. 9.
	Dejima	Sue Kasuya, Fukuoka	'91.12.14
Sweet potato	Miyazaki Aka	Ohtsuka Kushima, Miyazaki	'91.10.
Taro	Hasuba Imo	Nishihara Aso, Kumamoto	'91.11.
Citrus Unshu	Unsyu Okute	Yamakawa Yamato, Fukuoka	'91.12.
Persimmon	Fuyu	Haki Asakura, Fukuoka	'91.11.30

$$R = 10^3 M \cdot \frac{60 \cdot q \cdot x \cdot 10^{-6}}{22.40 \cdot \frac{T}{273.15} \cdot W}$$

$$= 0.7317 \cdot \frac{M \cdot q}{T \cdot W} \cdot x \cdots\cdots\cdots\cdots (1)$$

where R : respiration rate (CO_2mg/kg/hr)
M : molecular weight of CO_2 (= 44)
q : flow rate (l/min)
x : measured difference of CO_2 concentration (ppm)
T : surface temperature of sample (K)
W : weight of sample (kg)

RESULTS AND DISCUSSION

1. Temperature dependency equation of respiration

Arrhenius' equation and Gore's equation were used as equation of temperature dependency of respiration rate. Arrhenius' equation is used as equation of chemical reaction rate (Sutcliffe, 1981).

$$R = R_a \cdot \exp(-\alpha/T) \cdots\cdots\cdots\cdots (2)$$

where R : respiration rate (CO_2mg/kg/hr)
R_a : coefficient
α : temperature coefficient
T : temperature (K)

Gore's equation is celebrated as a equation of temperature dependency ,of respiration rate of fresh vegetables (Ogata, 1977), which is derived from Arrhenius' equation as approximation.

$$R = R_0 \cdot \exp\ (\beta\ t) \cdots\cdots\cdots\cdots (3)$$

where R : respiration rate (CO_2mg/kg/hr)
R_0 : value of R at 0°C
β : temperature coefficient
t : temperature (°C)

Using these two equations, temperature coefficients were determined by the least square method. Temperature dependency of respiration rate for Asparagus by Arrhenius' equation and by Gore's equation are shown in Fig. 2 and 3. The obtained respiration characteristics data of Asparagus was well fitted to these equations. It is preferred to select either of the above equations for the purpose in practical requirements.

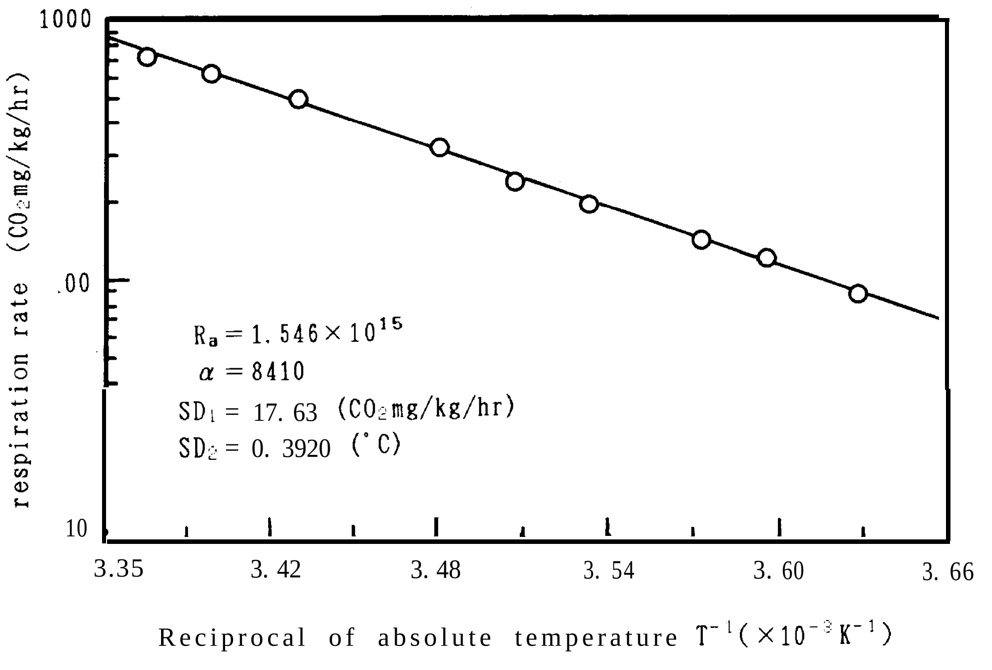


Fig. 2. Temperature dependency of respiration rate for asparagus (Eq. Arrhenius).

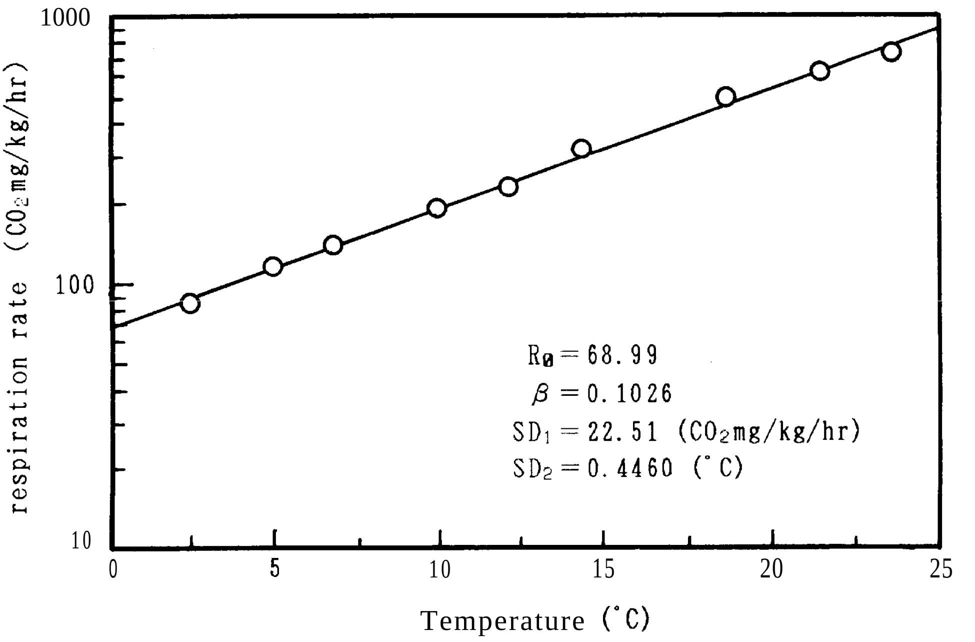


Fig. 3. Temperature dependency of respiration rate for asparagus (Eq. Gore).

2. Temperature coefficient

Calculated temperature coefficients are shown in Table 2. Results showed that the

Table 2. Temperature coefficient.

Materials	$R = R_a \cdot \exp(-\alpha/T)$ (CO_2mg/kg/hr)				$R = R_0 \cdot \exp(\beta t)$ (CO_2mg/kg/hr)			
	Ra	α	SD_1	SD_2	R_0	β	SD_1	SD_2
Spinach	2.144×10^{14}	8006	11.50	0.5784	41.83	0.09808	13.22	0.6643
Coronarium	9.355×10^{15}	8962	15.20	0.4033	55.74	0.1092	20.26	0.5205
Chinese cabbage	3.836×10^{6}	3418	1.366	1.147	14.41	0.04175	1.270	1.0498
Lettuce (Head)	1.893×10^{5}	2282	1.168	0.6451	45.08	0.02795	1.315	0.7246
Asparagus	1.546×10^{15}	8410	17.63	0.3920	68.99	0.1026	22.51	0.4460
Onion	1.327×10^{6}	3166	0.7701	0.8939	12.56	0.03844	0.8247	0.9608
Carrots	2.284×10^{9}	4883	4.732	0.6648	40.47	0.05953	5.356	0.7411
Turnip	8.732×10^{12}	7138	7.316	0.7547	33.24	0.06951	7.345	1.044
Potato (Dejima)	2.224×10^{8}	4496	1.688	1.033	16.11	0.05569	1.760	1.091
(May Queen)	1.194x104	2104	0.2289	1.2219	5.47	0.02569	0.2391	1.309
Sweet potato	2.404×10^{10}	5833	2.039	0.8040	13.26	0.07122	2.281	0.9109
Taro	1.123×10^{10}	5794	1.223	0.8514	7.07	0.07142	1.296	0.8482
Citrus Unshu	6.230×10^{12}	7401	4.898	1.094	11.23	0.08976	5.273	1.178
Persimmon	5.733×10^{10}	6214	0.7537	0.4212	7.75	0.07705	0.8925	0.4912

vegetable which has comparatively higher growth rate and less reservation period has comparatively higher respiration rate. The respiration rate (R_0) of leafy vegetables (food synthesizing organ) were comparatively higher than potatoes (the stored organ of the plants). The respiration rate of root vegetables and fruits were between them. Same as leafy vegetables, Asparagus, which has remarkably high stem growth, showed higher respiration rate.

For leafy vegetables, root vegetables, potatoes and fruits, temperature dependency of respiration rate by Arrhenius' equation is shown in Fig. 4, 5, 6 and 7. Spinach and

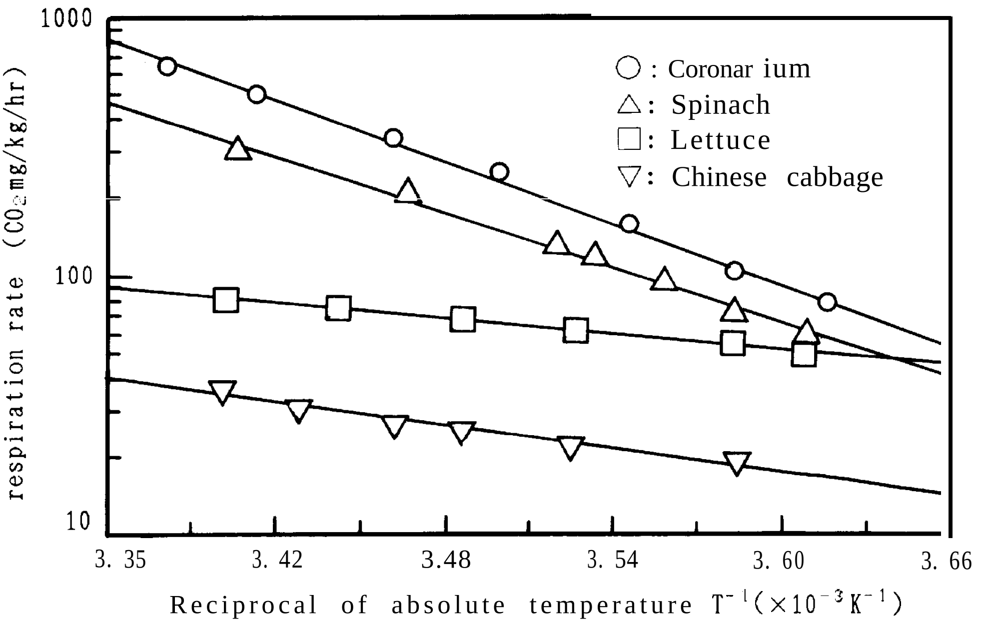


Fig. 4. Temperature dependency of respiration rate for leafy vegetables.

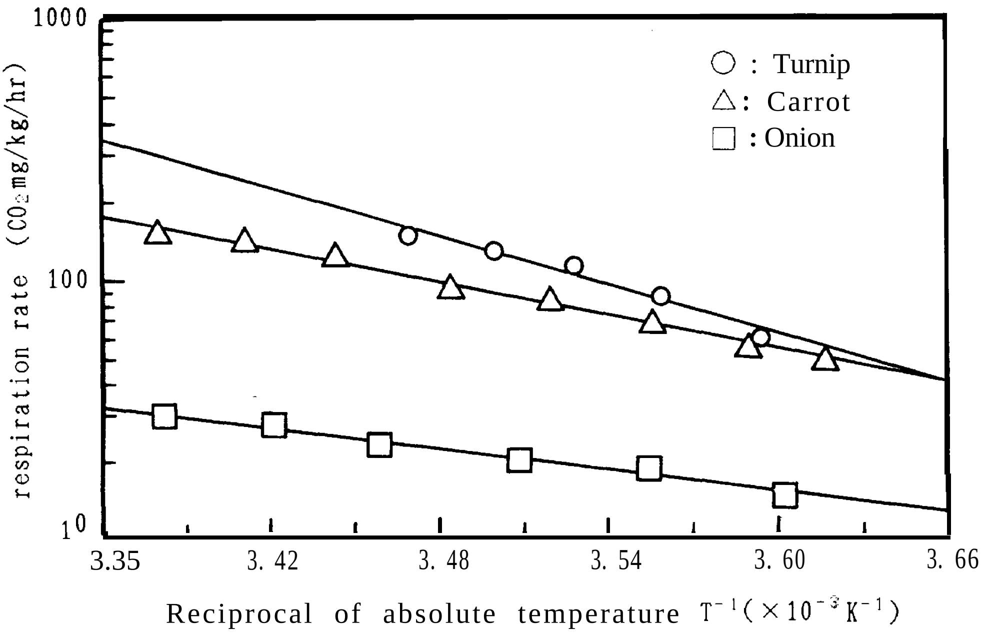


Fig. 5. Temperature dependency of respiration rate for root vegetables.

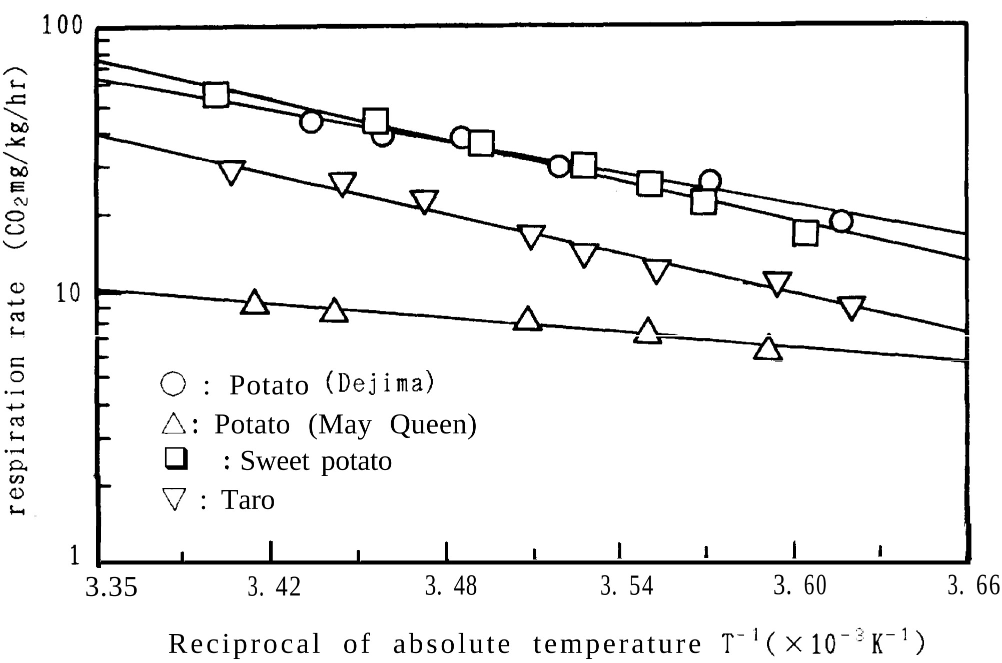


Fig. 6. Temperature dependency of respiration rate for potatoes.

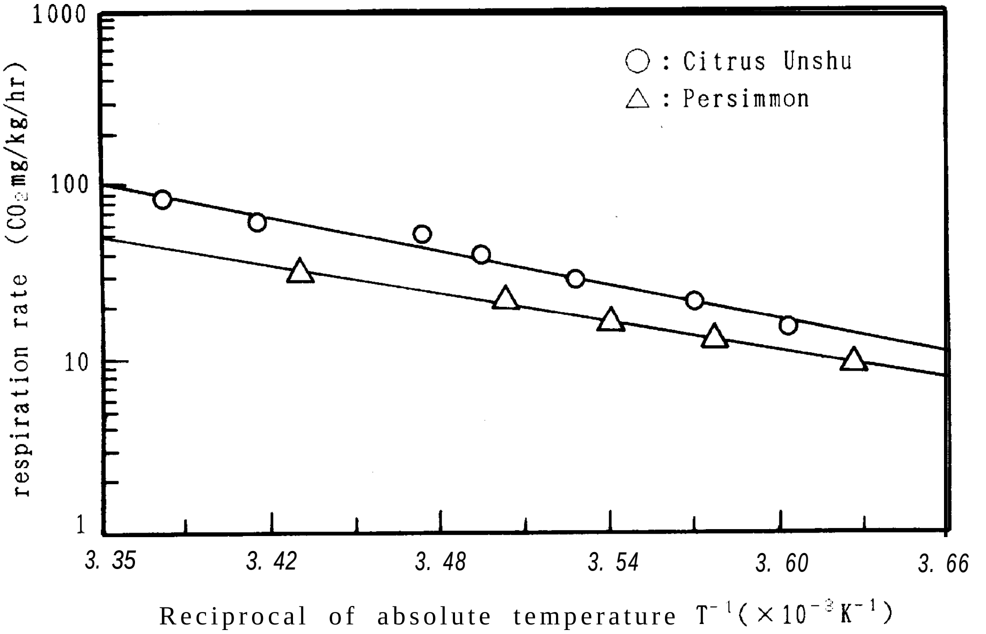


Fig. 7. Temperature dependency of respiration rate for fruits.

Coronarium having different leaf arrangement has higher respiration rates than that of the head type Lettuce and Chinese Cabbage. In root vegetables Turnip showed the same behavior as Carrot (topped) and higher respiration rate than that of Onion. Potato also showed the same behavior of temperature dependency, but lower respiration rate than the other vegetables. Specially potato variety of May-Queen showed the lowest respiration rate and it may be caused by cold storage before the experiment. In fruits, the temperature dependency characteristics of Citrus Unshu and Persimmon were look alike.

3. **Heat of respiration**

Heat of respiration is an important factor as a load in cold storage of fresh vegetables. But it is very difficult to measure directly and accurately. Conventional values of heat of respiration were generally estimated by respiration rate (Katoh, 1967. U.S. Dep. Agr., 1954). So in this study, heat of respiration was estimated by following equations based on oxidation of glucose.

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O_{(l)} + 2803\text{kJ} \cdots\cdots\cdots\cdots(4)$$

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O_{(g)} + 2539\text{kJ} \cdots\cdots\cdots\cdots(5)$$

Calorific values of these chemical reactions were obtained by standard formation enthalpy of both sides of each of these equations 4 and 5 (J. Chem. Soc., 1984). The conversion coefficient per CO_2 – lg was 10.61 (eq.4).

$$2803/(6\times 44) = 10.61\ (\mathrm{kJ}) \cdots\cdots\cdots\cdots (6)$$

The heat of respiration (Q_R) in kJ per ton per day was obtained by multiplying the respiration rate of milligrams of CO_2 per kilogram per hour with the factor of 10.61.

$$Q_R = 10.61 \times R \times 24 \cdots\cdots\cdots\cdots\cdots\cdots (7)$$

Temperature and the correspondent calculated values of heat of respiration are shown in Table 3. The values of heat of respiration were all a little higher than the

Table 3. Heat of respiration.

Materials	Heat of respiration at various temperature (kJ/ton/day)					
	0°C	5°C	10°C	15°C	20°C	25°C
Spinach	10170 (4430~5170)	17230 (8020~13400)	28640	46780 (31130~51910)	75140 (39990~66680)	118790 –
Coronarium	13450	24250	42840	74190	126090	210540
Chainese cabbage	3590	4500	5580	6890	8430	10250
Lettuce (Head)	11330 (1370~3900)	11160 (3060-4640)	15220	17500 (7390~10450)	20030 (11820~13930)	22830 (16990~21210)
Asparagus	16760 (6540~13930)	29150 (13720~24370)	49710 –	83230 (26910~54340)	136920 (40410~62460)	221520 (86310~110470)
Carrot	10020 (2220~4750)	13810 (2950~4750)	18830	25400 (6010~12450)	33910 (10660~22050)	44840
Onion	3130 (1010~1680)	3850 (1340~2180)	4710 (1970~2930)	5720 (2720~3980)	6900 (3140~5020)	8270 –
Turnip	8250 (2010)	11970 (2220~2320)	17130	24210 (4960~5590)	33820 (5590~5800)	46720 –
Potato (Dejima)	4020	5410	7200	9480	12370	16000
(May Queen)	1370 (920~2260)	1580 (1050~1680)	1800 (1420~1880)	2050 (1680~3140)	2320 (2090~3770)	2620
Sweet Potato	3260	4780 –	6920 –	9900 (4540~5590)	13980	19510 –
Taro	1750	2570	3710	5290	7460	10390
Citrus Unshu	2710	4420	7070	11120	17240	26320
Persimmon	1920	2900 (1370)	4300 –	6290 (2740~3270)	9090 (4640~5590)	12960 (6750~9290)

conventional values (Katoh, 1967. U.S. Dep. Agr., 1954) (parenthesized values under the each relevant entries in the Table 4). In each vegetable the values were about three times of the conventional values under 0°C . The higher the temperature smaller the difference between the calculated value and the conventional. In the conventional method of closed system the accumulation of CO_2 itself may retared the respiration rate and also affects on the measurement accuracy adversely, whilst in this study the difference of CO_2 concentration was momentarily measured by modern precise ventilatory method with the help of infrared gas analyzer.

4. The temperature coefficient (Q_{10})

Temperature coefficient Q_{10} is an index for estimation of temperature effect in biological processors. Q_{10} is generally about 2 and becomes higher in lower temperatures. Q_{10} values of respiration rates were obtained by temperature coefficient determined by Arrhenius' equation. The results are shown in Table 4.

Table 4. Values of Q_{10}.

Materials	Q_{10}			
	0 °C～10°C	5 °C～15°C	10°C～20°C	15°C～25°C
Spinach	2.815	2.715	2.624	2.539
Coronarium	3.186	3.059	2.944	2.838
Chinese cabbage	1.556	1.532	1.510	1.489
Lettuce (Head)	1.343	1.329	1.317	1.304
Asparagus	2.966	2.856	2.754	2.661
Onion	1.506	1.484	1.464	1.446
Carrots	1.880	1.839	1.801	1.765
Turnip	2.517	2.437	2.363	2.295
Potato (Dejima)	1.788	1.752	1.719	1.688
(May Queen)	1.317	1.300	1.288	1.277
Sweet potato	2.126	2.070	2.019	1.972
Taro	2.115	2.060	2.010	1.963
Citrus Unshu	2.604	2.518	2.439	2.367
Persimmon	2.233	2.171	2.114	2.061

The value of Q_{10} of all kinds of vegetables is nearly 2, and it is lower than the value of various vegetables under 0°C to 24°C measured by Platenius (Platenius, 1942). Calculated values have no difference at various temperatures, but they are indexes for investigation of respiration of vegetables.

CONCLUSIONS

The relationship between respiration rate and temperature of thirteen kinds of Japanese vegetables were measured, and the data of this study will contribute to the fundamental data for designing a rational storage equipment, estimation of quality of vegetables in storages and for storage physiology studies.

The results showed that ;

1) Measured results were fitted to Arrhenius' equation and Gore's equation of temperature dependency.
2) Rate of respiration increases in the order of leafy vegetables, root vegetables, fruits and potatoes.
3) The heats of respiration were all a little higher than the conventional values.
4) The values of Q_{10} were nearly 2.

Because these kind of data is little available at the present the results of this study will be helpful not only for storage design but also physiology studies etc.

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