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Relationship between cumulative heat units and fruit-body emergence of ectomycorrhizal fungus *Tricholoma bakamatsutake* in the fields

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The relationship between cumulative heat units and fruit-body emergence of *Tricholoma bakamatsutake* was examined by using the method used for estimating dates of adult emergence of insects. Fruit-body numbers at a study site at Tateyama, Chiba Prefecture and records at a weather station near the site from 1987 to 1993 were used. For the seven years, daily average temperatures above the developmental threshold were cumulated for the days following induction of fruit-body development. The developmental threshold was taken to be 0°C, and the day when the daily minimum temperature fell to near 20°C in each year was taken as the day of induction of fruit-body development. A linear relationship between fruit-body numbers and daily average temperatures was observed as follows: $Y=0.00376X+1.873$ ($r=0.810$), where Y is the probit of percentage of cumulative fruit-bodies, and X is the heat units above 0°C cumulated for the days following induction of fruit-body development. X for $Y=5$, which represents the cumulative emergence of 50% of fruit-bodies, was estimated to be 832 day-degrees.

Key Words——cumulative heat units; ectomycorrhizal fungus; fruit-body emergence; temperature effect; *Tricholoma bakamatsutake*.

Many environmental factors affect primordium formation in Homobasidiae including mushroom-forming ectomycorrhizal fungi (Suzuki, 1979). Concerning edible ectomycorrhizal fungi, the relations between fruit-body formation and climatic factors have been studied mainly for *Tricholoma matsutake* (S. Ito et Imai) Sing. (Kinugawa, 1963; Kawakami, 1990), while few such studies have been conducted for the allied species *T. bakamatsutake* Hongo (Kuraishi and Narita, 1953).

In ecological studies of insects, on the other hand, dates of adult emergence were successfully estimated by using probits of percentages of cumulative numbers of adults caught and cumulative heat units, day-degrees, above a developmental threshold (Ito and Endo, 1970; Fujiie, 1980). In this paper, the same method was used to examine the relationship between heat units above 0°C cumulated for the days following induction of fruit-body development of *T. bakamatsutake* and probits of percentages of cumulative numbers of fruit-bodies.

Materials and Methods

The study was conducted at a site in Tateyama, Chiba Prefecture, the environmental condition of which has been described elsewhere (Terashima et al., 1993). The numbers of fruit-bodies of *T. bakamatsutake* which emerged in the study site and the emergence dates were recorded from 1987 to 1993. Fruit-body emergence was noticed during the period when the shape of pileus was convex, the period after the partial veil was broken and before the pilus was broadly unborate. Meteorological records at Tateyama Weather Station, 7 km from the study site, were used. The monthly average temperature and rainfall during August and October for these seven years were compared to those of the "normal" year, which is the average from 1969 to 1990 (Table 1).

Daily average temperatures of the seven years at the weather station above a developmental threshold were

Table 1. Monthly average temperature and rainfall compared with data of the normal year[1].

Year	Temperature[2] (°C)			Rainfall[3] (%)		
	Aug.	Sep.	Oct.	Aug.	Sep.	Oct.
1987	0.6	−0.3	1.0	31	132	85
1988	0.4	0.2	−0.3	134	176	71
1989	0.1	1.7	−0.4	239	68	149
1990	1.5	1.3	1.3	67	145	85
1991	−0.5	1.0	0.4	124	133	270
1992	−0.2	−0.3	−0.4	33	46	175
1993	−1.4	−0.4	−0.5	145	107	83

[1] The data were from Tateyama Weather Station.
[2] Difference from the temperature of the "normal" year, which is the average from 1969 to 1990: Aug., 25.9°C; Sep., 22.9°C; Oct., 17.5°C.
[3] Ratio to the data of the "normal" year: Aug., 143.3 mm; Sep., 216.8 mm; Oct., 218.3 mm.

cumulated after the days when fruit-body development was induced in each year. Since the theoretical developmental threshold for fruit-body formation of *T. bakamatustake* was unknown, it was taken as 0°C.

All fruit-bodies of *T. matsutake* in a certain area are reported to be initiated synchronously (Kinugawa, 1963). Here the day of induction of fruit-body development was estimated as follows. Daily minimum temperatures of each year were smoothed by using the moving average method in five terms. The day on which the daily minimum temperature fell to near 20°C from the continuously higher temperatures of summer was assumed to be the day when most of fruit-bodies were induced to develop in each year. For comparison with the daily minimum temperatures at the weather station, the daily minimum soil temperatures of the organic layer, where surfaces of mycelial blocks of *T. bakamatsutake* are located (Terashima et al., 1993), were measured at the study site in August and September from 1988 to 1992.

Percentages of cumulative fruit-bodies were transformed to probability units, probits, by the probit method (Finney, 1978). A linear regression equation between

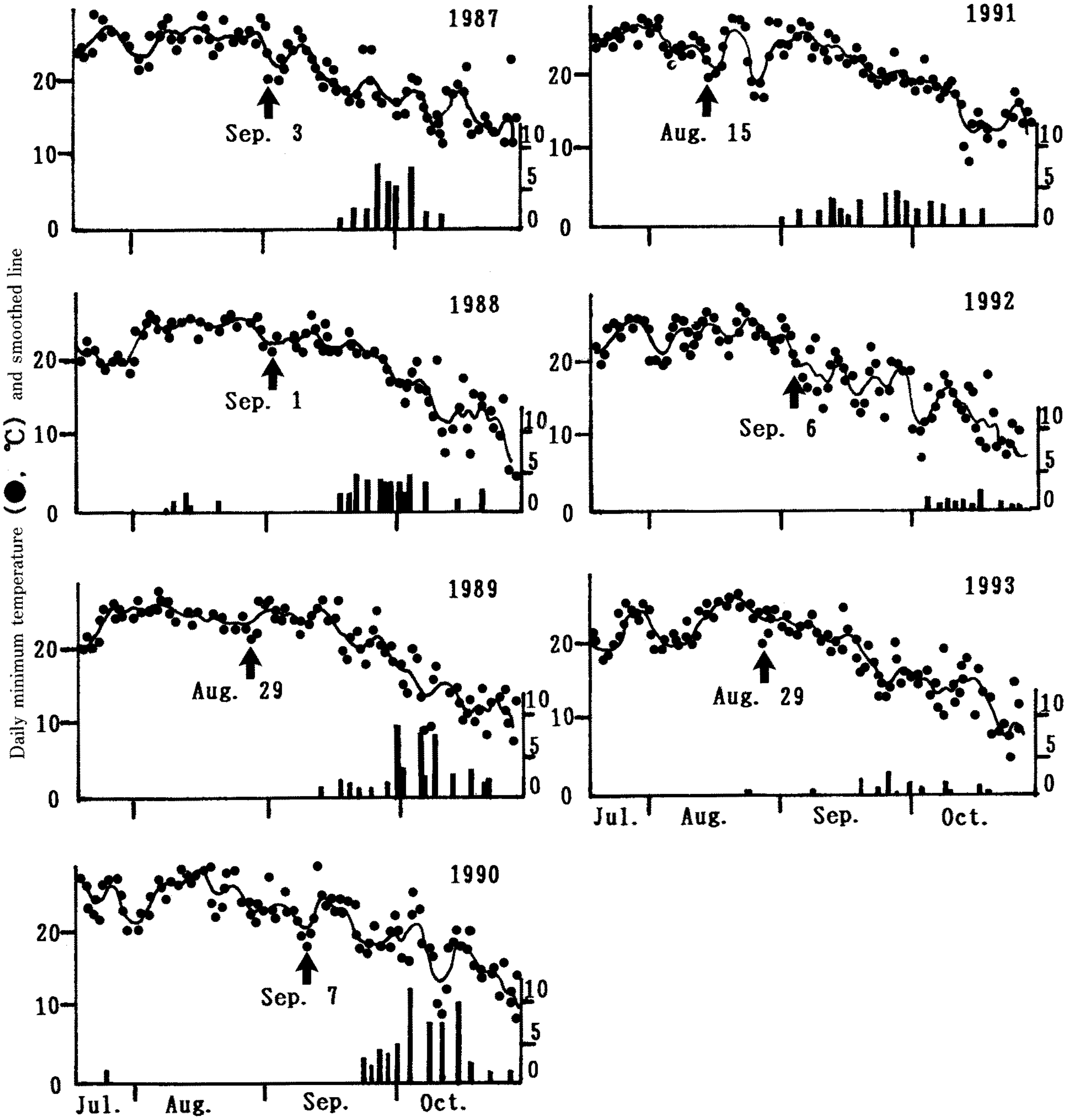

Fig. 1. Daily minimum temperatures, smoothed lines, and numbers of fruit-bodies of *T. bakamatsutake* emerging from late July through October from 1987 to 1993.
An arrow indicates the estimated day when fruit-body development was induced.

the probits of percentages of cumulative fruit-bodies and the cumulative heat units was then calculated based on the combined data of the seven years, and the day-degree of 50% fruit-body emergence was estimated.

Results

Estimation of days when fruit-body development was induced Daily minimum temperatures, the smoothed lines and numbers of fruit-bodies emerging from late July through October in the seven successive years from 1987 are shown in Fig. 1. The days on which fruit-body development was induced were assumed to be Sep. 3, Sep. 1, Aug. 29, Sep. 7, Aug. 15, Sep. 6 and Aug. 29 in 1987, 1988, 1989, 1990, 1991, 1992 and 1993, respectively. The average daily minimum ground-surface temperatures in August and September from 1988 to 1992 at the study site were only 0.1°C lower than the average daily minimum temperatures at the weather station. The correlation coefficients of these two daily minimum temperatures for the two months were all one, which meant the two daily minimum temperatures had a completely linear relationship. Fruit-bodies emerged mainly in September and October, but occasionally earlier, in July in 1990, and in August in both 1988 and 1993.

Percentages of cumulative fruit-body numbers against calendar dates Fig. 2 shows percentages of cumulative fruit-bodies of *T. bakamatsutake* against calendar dates between September and November from 1987 to 1993. The fruit-bodies began to emerge earliest in 1991 and latest in 1992. The difference in the first emergence date between these two years was 35 days.

Probits of percentages of cumulative fruit-body numbers The probits were plotted against cumulative heat units as shown in Fig. 3. The fruit-body emergence was estimated by the following linear regression equation:

$$Y=0.00376X+1.873,$$

based on the combined data from 1987 to 1993. Here Y is the probit of percentage of cumulative fruit-body numbers and X is the cumulative heat units above 0°C after the day of induction of fruit-body development. The right shoulders of the plotted data of 1989 and 1991 were downward compared to the rest.

Estimation of date of 50% cumulative emergence of fruit-bodies X for $Y=5$, which means 50% cumulative fruit-body emergence, was estimated to be 832 day-degrees based on the combined data. As shown in Table 2, the regression equation for each year was calculated based on the data for the respective year. Xs for $Y=5$ and the dates for the Xs cumulated after the day of induction of fruit-body development were estimated. These 50% emergence dates for individual years were compared with the dates estimated by using the 832 day-degrees on the basis of the combined data described above. The differences between the dates for individual years and those based on the combined data of the seven years were from −11 to +9 days.

Discussion

Primordium formation in higher fungi is affected by physical and chemical factors, such as light, temperature, gravity, injury, obstacles, nutrient supply, gas, substrate moisture and physiologically activating substance (Suzuki, 1979). In woodlands, temperature and substrate moisture, which is influenced by amount of rainfall, greatly influence fruit-body emergence (Wilkins and Harris, 1946; Shimono, 1988). Concerning the ectomycorrhizal fungus *Tricholoma matsutake*, it was reported that

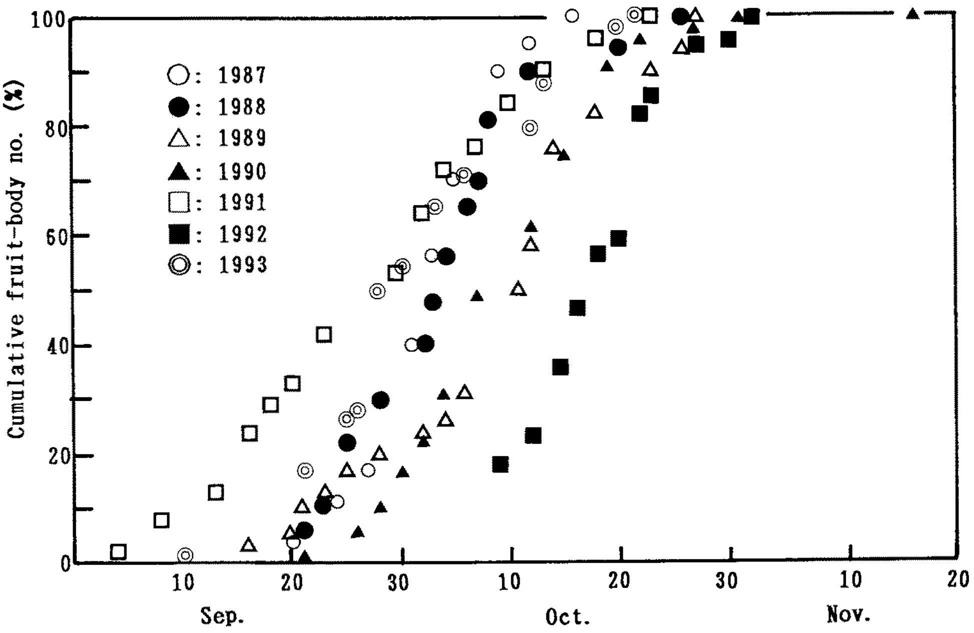

Fig. 2. Percentages of cumulative fruit-body numbers of *T. bakamatsutake* between September and November from 1987 to 1993.

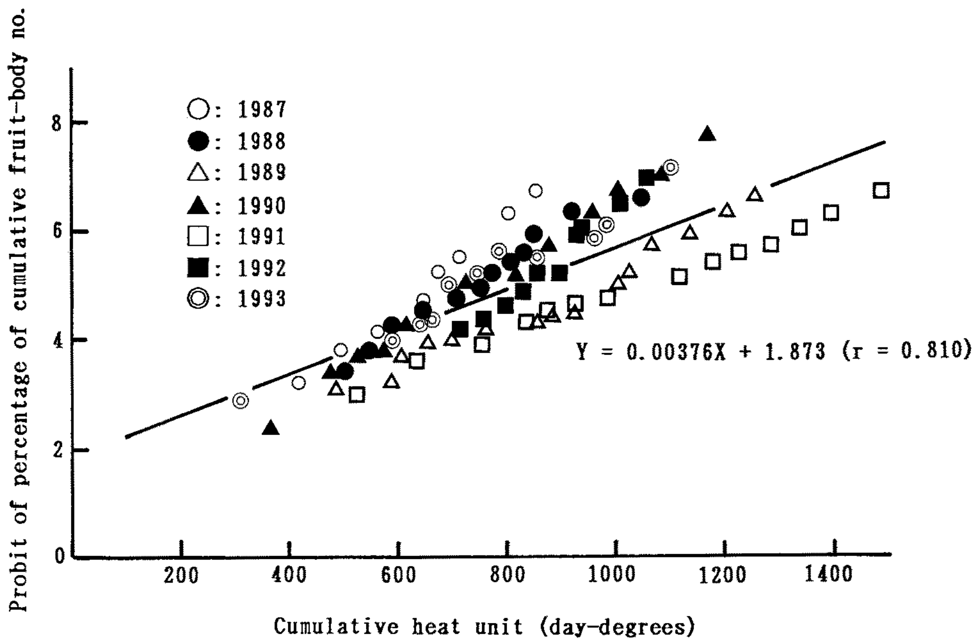

Fig. 3. Probits of percentages of cumulative fruit-body numbers of *T. bakamatsutake* against cumulative heat units.

temperature affects both primordium formation and fruit-body development (Kinugawa, 1963) and rainfall is related to fruit-body development (Kawakami, 1990). Here primordium formation was assumed to be induced on a certain day, and by using cumulative heat units fruit-body emergence was estimated.

The cumulative heat units above 0°C after the day of induction of fruit-body development showed linear relationships with the probits of cumulative percentages of fruit-bodies over the seven years studied. The probits of percentages of cumulative fruit-body numbers in 1989 and 1991 in Fig. 3 were lower than those in the other years. The Xs for Y=5 in 1989 and 1991 were larger than the others. This anomaly can be explained by the temperature data in Table 1: in these years, temperatures again rose above 20°C for about one month after the day of induction of fruit-body development. In *T. matsutake*, it was also reported that continuously higher temperatures after the day of induction of fruit-body development resulted in less fruit-body emergence (Kinugawa, 1963). The low and high rainfalls of September 1989 and October 1991, respectively, might also have contributed to these lower probits. Rainfall after the day of induction of fruit-body development is reported to be related to fruit-body emergence (Kawakami, 1990).

Under natural conditions, fruit-bodies of *T. bakamatsutake* were reported to emerge at soil temperatures in the mycelial layer ranging from 18.5 to 20.0°C, compared with 18.0 to 19.5°C for *T. matsutake* (Kuraishi and Narita, 1953). All fruit-bodies of *T. matsutake* in a certain area initiated synchronously when the temperature of the mycelial layer fell to 19°C or below in autumn (Kinugawa, 1963), but the minimum soil temperature in the mycelial layer for inducing fruit-body development is

Table 2. Date of 50% cumulative emergence of fruit-bodies of *T. bakamatsutake*.

	Combination from 1987 to 1993	1987	1988	1989	1990	1991	1992	1993
Regression of percentage of cumulative fruit-body numbers (Y) for cumulative heat units (X)								
Regression coefficient	0.00376	0.00814	0.00593	0.00442	0.00621	0.00365	0.00766	0.00504
Intercept of regression line	1.873	−0.380	0.580	0.768	0.352	1.140	−1.303	1.250
X for Y=5 (A)	832	661	745	957	748	1058	822	744
Correlation coefficient	0.810	0.995	0.987	0.978	0.996	0.996	0.953	0.988
Date of 50% cumulative fruit-body numbers estimated by using A of respective year (B)		Oct. 2	Oct. 3	Oct. 8	Oct. 9	Sep. 27	Oct. 16	Sep. 30
Date of 50% cumulative fruit-body numbers estimated using A of the combined data (C)		Oct. 11	Oct. 8	Oct. 1	Oct. 14	Sep. 16	Oct. 17	Oct. 5
Difference between B and C		+9	+5	−7	+4	−11	+1	+5

presently unknown for *T. bakamatsutake*. In this paper the day when fruit-body development was induced was estimated by judging the day when the daily minimum air temperature at the weather station fell to near 20°C before the main emergence period of fruit-bodies in September and October. The daily minimum air temperatures during August and September from 1988 to 1992 at the weather station were about the same as the daily minimum temperatures of the ground-surface at the study site where surface of mycelial blocks of *T. bakamatsutake* were located.

A linear relationship was found between the cumulative heat units above the developmental threshold and the probits of percentages of cumulative adult emergence in insects (Ito and Endo, 1970; Fujiie, 1980). This developmental threshold could be calculated from the developmental rates under several constant experimental temperature conditions, because both showed linear relationships (Noda, 1989). Developmental thresholds of about 10 to 11°C were used for estimation of adult emergence of *Hyphantria cunea* Drury (Ito and Endo, 1970) and of *Bucculatrix pyrivorella* Kuroko (Fujiie, 1980). For mycelial growth, the developmental threshold could be estimated by using the mycelial growth rate at different temperatures (Terashima, 1994), but fruit-body development after primordium formation cannot be tested in vitro. Here, for prediction of fruit-body emergence of *T. bakamatsutake*, the developmental threshold was taken to be 0°C.

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Literature cited

Finney, D. J. 1978. "Statistical method in biological assay, 3rd ed.," Charles Griffin, London. 508 p.

Fujiie, A. 1980. Total effective temperatures and critical daylength in relation to the seasonal life cycle of the pear leaf miner, *Bucculatrix pyrivorella* Kuroko. Jpn. J. Appl. Ent. Zool. **24**: 251-253. (In Japanese.)

Ito, Y. and Endo, T. 1970. Biology of *Hyphantria cunea* Drury (Lepidoptera: Arctiidae) in Japan XII. Prediction of adult emergence. Jpn. J. Ecol. **20**: 59-62.

Kawakami, Y. 1990. Studies on factors affecting the occurrence of *Tricholoma matsutake* (S. Ito & Imai) Sing.: The relation between precipitation, temperature below the ground and the occurrence of fruit body. Bull. Hiroshima Pref. For. Exp. Stn. **24**: 7-20. (In Japanese.)

Kinugawa, K. 1963. Ecological studies on the development of fruit-body in *Armillaria matsutake* Ito et Imai: Analysis of growth curves. Bull. Univ. Osaka Pref., Ser. B **14**: 27-60. (In Japanese.)

Kuraishi, H. and Narita, D. 1953. Studies in mycorrhizal fungi II. An *Armillaria* species locally known as "bakamatsutake" and its habitat. Ecol. Rev. **13**: 169-177.

Noda, H. 1989. Developmental zero and total effective temperature of three rice planthoppers (Homoptera: Delphacidae). Jpn. J. Appl. Ent. Zool. **33**: 263-266. (In Japanese.)

Shimono, Y. 1988. Effects of climatic conditions on the fruiting of *Russula* species in a *Castanopsis cuspidata* forest in Kyoto. Trans. Mycol. Soc. Japan **29**: 73-84. (In Japanese.)

Suzuki, A. 1979. General review on environmental factors affecting primordium formation in Homobasidiae. Trans. Mycol. Soc. Japan **20**: 253-265. (In Japanese.)

Terashima, Y. 1994. Change in medium component and morphology due to mycelial growth of ectomycorrhizal fungus *Tricholoma bakamatsutake*. Mycoscience **35**: 153-159.

Terashima, Y., Tomiya, K., Takahashi, M. and Iwai, H. 1993. Distribution and characteristics of shiros of *Tricholoma bakamatsutake* in a mixed forest of *Pasania edulis* and *Castanopsis cuspidata* var. *sieboldii*. Trans. Mycol. Soc. Japan **34**: 229-238.

Wilkins, W. H. and Harris, G. C. M. 1946. The ecology of the larger fungi V. An investigation into the influence of rainfall and temperature on the seasonal production of fungi in a beechwood and a pinewood. Ann. Appl. Biol. **33**: 179-188.