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Changes in Anthesis, Grain Filling and Grain Yield Accompanied by Hastening of Heading in Winter Wheat and Barley

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秋播 大・小麥의 早期出穗에 따른 開花, 登熟 및 收量性 變化

金 石 東*・權 容 雄**

ABSTRACT

Heading time was hastened by the combination of seeding time and longday treatment in order to elucidate the effect of early heading on earliness in maturity, vegetative growth and grain yield in five barley varieties and four wheat varieties under field conditions in Suwon, Korea, 1978-79. About 15 days of earliness in heading accelerated only 2 to 6 days in maturity. Furthermore, the duration of grain fill was not much prolonged comparing with the extension of days from heading to maturity, because of the extension of periods from heading to anthesis at lower temperature resulting in somewhat greater final grain weight. Periods from heading to anthesis and from anthesis to maturity were negatively correlated with the air temperature. In early heading, leaf area at 10 days after anthesis and net assimilation rate were much limited, and although leaf area duration got larger, presumably, it could not make up for the reduction of grain yield. Grain yield per plant reduced noticeably in early heading. This was mainly caused by the reduction of spike number and grain number per spike.

INTRODUCTION

Overlapping of growing periods of wheat or barley with paddyrice or upland legumes has long been caused a severe competition between harvesting of wheat or barley and the transplanting of paddyrice or seeding of upland legumes. This phenonmenon leads to competition for working labours during the same time under the most prevailing system of double cropping in Korea.[14] For this reason, much efforts has been made to solve this problem by improving earliness in maturity of wheat and barley resulting in release of early maturing varieties with high productivity. Selection effort for earliness in maturity had been focussed on early heading because maturing time of wheat and barley was forcedly determined by the environmental conditions such as high temperature and drought in the late season of grain filling. In the meanwhile, too much acceleration of heading time brought the reduction of grain yield. Therefore, the direction of breeding of wheat and barley rearranged to two, one; high yield production, and another; earliness in maturity maintaining a resonable level of grain yield since 1979[1].

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Temperature has a pronounced effect during the period of grain fill, which keeps longer at lower temperatures, resulting in greater final grain weight[3,13]. Hashimoto et al.[5] observed that inter-varietal difference existed in number of days from heading to anthesis, and from anthesis to maturity in wheat and that these traits were negatively correlated with mean air temperature. Sofield et al.[8] reported that grain filling periods took over 80 days under 15/10°C, and about 45 days under 30/25°C, day/night resulting in 60 mg and 35 mg of grain weight, respectively. In an experiment for elucidation of the effects of temperature on the grain filling, in wheat. Cho et al.[2] reported that the durations from heading to anthesis of wheat plants grown at 13°C and 16°C constant temperature were 12 and 7 days, respectively. and that daily mean temperature showed significant negative correlations with heading date and duration from heading to anthesis, both indicating $r = -0.79^{**}$.

Evans et al.[4] reported that 90-95% of the carbohydrate in grain was derived from carbon dioxide fixation after anthesis and Cho et al.[2] suggested that leaf area in wheat reached its peak about 15 days after heading. In this regard, it may be favorable for grain yield to maintain photosynthetic tissue as great as possible after anthesis. On the other hand, since grain fill is much controlled by temperature, the duration and rate of photosynthesis have to be taken into consideration in relation to the temperature. In these points, leaf area duration (LAD) and net assimilation rate (NAR) are very useful parameters for evaluation of potential photosynthesis[13] because LAD takes account of both extent and duration of photosynthetic area and NAR represents the rate of photosynthesis per unit leaf area.[9,11]

Conditions accelerating floral induction tend to reduce spikelet number by hastening the formation of the terminal spikelets.[4] Rawson[7] suggested that under conditions of floral induction, spikelet number, grain number, and final yield per spike reduced.

This study was conducted to elucidate changes in anthesis, grain filling, and grain yield accompanied by hastening of heading time in winter wheat and barley varieties under field condition. Additionally, relationship between heading time and amount of vegetative growth, and the efficiency of early heading on maturing time were evaluated.

MATERIALS AND METHODS

Four winter wheat varieties, Suwon 210, Olmil, Chokwang, and Norin 16, and five winter barley varieties, Jogangbori, Milyang 6, Olbori, Dongbori 1, and Bunong were sown in the field plots in College of Agriculture, Seoul Nat'l Univ. Suwon, Korea, 1978. There were three units of plots in which the seeds were sown on October 13 in the first two plots and on October 30 in the third plots. To achieve earliness and difference in heading time, the plants in the first plot were illuminated during the night by 100 watt incandescent lamps which were arranged at every 1 meter interval and 1.5 meter over the soil surface from March 25 to heading time. Each plot contained 2 rows, 1.2 m long with 40 cm of row space for each variety, and 3 plants were maintained at every 10 cm on the rows. The soil was deeply ploughed more than 30 cm and fertilized with 6 kg of nitrogen, 9 kg of P_2O_5, and 7 kg of K_2O per 10a, respectively, just prior to sowing. In addition, 6 kg of nitrogen per 10a was topdressed at early spring when the plants began to regrow.

Every spike was tagged when the neck of spike reached at the auricle of flag leaf, and the heading date for that spike was written on the same tag. Heading time for a variety in a plot was judged when 40% of spikes in the plot were heading. Anthesis of each spike was determined when florets more than one per spike were opening. The variation in the period from heading to anthesis was determined. Heading was observed at 1700 to 1900 and anthesis at 1000 to 1200 for barley, and 1400 to 1600 for wheat.

All of the observations were based on the spikes tagged just at the heading time for the plot, except for the variation of the period from heading to anthesis and for determination of grain yield.

Samplings for measurement of vegetative growth and grain weight were taken at 10, 20, 25, 30, 35, and 40 days after anthesis. On each sample date, uniformal five culms from each plot were cut off at ground level, immediately placed in polyethylene bags and taken to the laboratory, where they were placed in a ca. 5°C refrigerator. The five culms were removed from the refrigerator to separate leaf blades and spikes. Each culm represented a replicate. Leaf area was determined with a leaf area meter (Green-leaf Areameter, Type GA-3, KIYA, Japan). Grains weighed after oven-dry for 24 hrs at 80°C.

Statistical analysis revealed a significant polynominal relationship between grain dry weight and the number of elapsed days after sampling began. Hence, regression equation $y=a+bx+cx^2+dx^3$, where y and x stand for grain dry weight and the number of days after anthesis, respectively, were used for each plot of the varieties. The date of predicted maximum was calculated as the maximal points on the equations.[6]

Leaf area duration (LAD') for the period of grain fill was calculated by integral of leaf area over time from anthesis to maturity. Here, LAD' means integral of leaf area over time, not leaf area index which is used for Watson's LAD.[11] The net assimilation rate (NAR) was computed by dividing the grain dry weight by LAD'.

Table.1. Relationship between heading date and maturation in early varieties of wheat and barley.

Crops	Varieties	Seeding	Longday treatment[1)]	Heading	Anthesis	Maturity	Days from heading to muturity	Grain filling period (days)	Grain yield/ plant (g)	Index (%)
Wheat	Suwon 210	Oct. 13	LD	April 30	May 10	June 14	45	35	3.70	32.7
		Oct. 13	N	May 6	14	16	41	33	8.53	75.5
		Oct. 30	N	May 13	18	18	36	31	3.77	33.3
	Olmil	Oct. 13	LD	April 30	May 10	June 16	47	37	4.97	44.0
		Oct. 13	N	May 6	13	17	42	35	10.70	94.7
		Oct. 30	N	May 15	20	18	34	29	4.33	36.6
	Chokwang	Oct. 13	LD	May 5	May 12	June 18	46	37	6.03	53.4
		Oct. 13	N	May 8	18	20	41	33	11.30	100.0
		Oct. 30	N	May 16	20	21	36	32	5.90	52.2
	Norin 16	Oct. 13	LD	May 2	May 12	June 18	47	37	6.27	55.5
		Oct. 13	N	May 9	15	19	43	35	10.87	96.2
		Oct. 30	N	May 14	20	20	36	31	3.57	31.6
Barley	Jokangbori	Oct. 13	LD	April 25	May 2	June 3	39	32	5.13	48.0
		Oct. 13	N	April 29	4	5	36	32	10.70	100.0
		Oct. 30	N	May 4	9	5	32	27	4.73	44.2
	Milyang 6	Oct. 13	LD	April 25	May 1	June 5	41	35	9.37	87.5
		Oct. 13	N	May 2	7	6	35	30	10.00	93.5
		Oct. 30	N	May 5	5	7	33	29	6.93	64.8
	Olbori	Oct. 13	LD	April 24	May 1	June 5	42	35	4.83	45.2
		Oct. 13	N	May 2	May 6	5	34	30	8.03	75.1
		Oct. 30	N	May 6	May 9	6	31	28	5.30	49.5
	Dongbori 1	Oct. 13	LD	April 26	May 3	June 6	41	34	5.33	49.8
		Oct. 13	N	May 3	8	6	34	29	9.73	91.0
		Oct. 30	N	May 6	May 10	6	31	27	3.60	33.6
	Bunong	Oct. 13	LD	April 28	May 3	June 7	40	35	9.80	91.6
		Oct. 13	N	May 2	6	7	36	32	9.67	90.3
		Oct. 30	N	May 10	10	13	34	30	5.70	53.3

1) LD: Longday treatment from March 25 to heading, N : Natural

RESULTS AND DISCUSSION

Difference in seeding time and longday treatment result in the variations of 16 and 15 days in heading time for wheat and barley, respectively, i.e, 30 April to 16 May for wheat and from 24 April to 9 May for barley(Table 1.). Changes in maturation time caused by the difference in heading time were not so as the extent of difference in heading time. Only 2 to 3 days difference resulted from that of heading time. Days from heading to maturity were divided to days from heading to anthesis and to days from anthesis to maturity as noted by Hashimoto et al.[5] Early heading required longer period for anthesis and also more or less long period for maturity from anthesis. Earliness of 15 days in heading for wheat and 9-10 days for barley elapsed about 13 days for wheat and 7-11 days for barley. For this reason, the actual period of grain fill was prolonged only 4-7 days. To elucidate the reason for the extension of days for anthesis and maturity, the mean air temperature and days from heading to anthesis or days from anthesis to maturity were figured as shown in Fig. 1 and Fig. 2. It was recognized that these number of days were negatively correlated with air temperature. Consequently, hastening of heading contributed little to early maturing and to extension of grain filling period resulting in the reduction of grain yield. On the other words, these relationships suggest that earliness in maturity could not easily achieved from hastening of heading time, if any, the efficiency might be small because of extension of periods from heading to anthesis and from anthesis to maturity caused by the effect of low temperature during the periods in early heading under the field conditions. In addition, it might be difficult to avoid the reduction in grain yield caused by early heading.

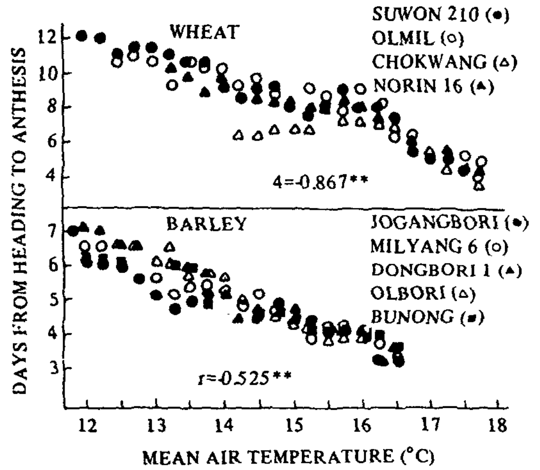

Fig. 1. Relationship between mean air temperature and days from heading to anthesis.

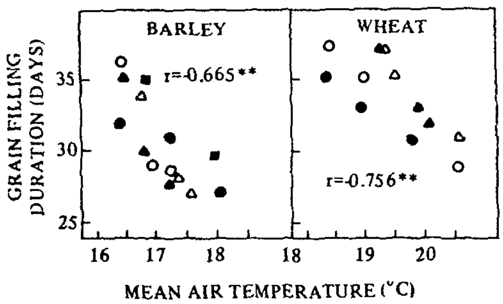

Fig. 2. Relationship between grain filling duration and mean air temperature for the filling period. Symbols are the same as in Fig. 1.

Patterns of progressive change in grain weight were illustrated in Fig. 3. Initial lag was found in the rate of grain filling from anthesis until about 20 days after anthesis. Grain filling period from anthesis to the time of peak point of grain weight was prolonged in early heading resulted in greater final grain weight but short in late heading. This trend was also shown in an experiment by Sofield et al.[8] in which the effect of temperature on the rate and duration of grain filling was typically represented, though it was confined within a variety of wheat. Of barley varieties tested, Jogangbori and Bunong showed somewhat different feature in the final grain weight, which had higher grain weight in late heading instead of early heading. In this case, early heading didn't have positive effect on grain weight as well as earliness in maturity.

Changes in leaf area, leaf area duration (LAD),

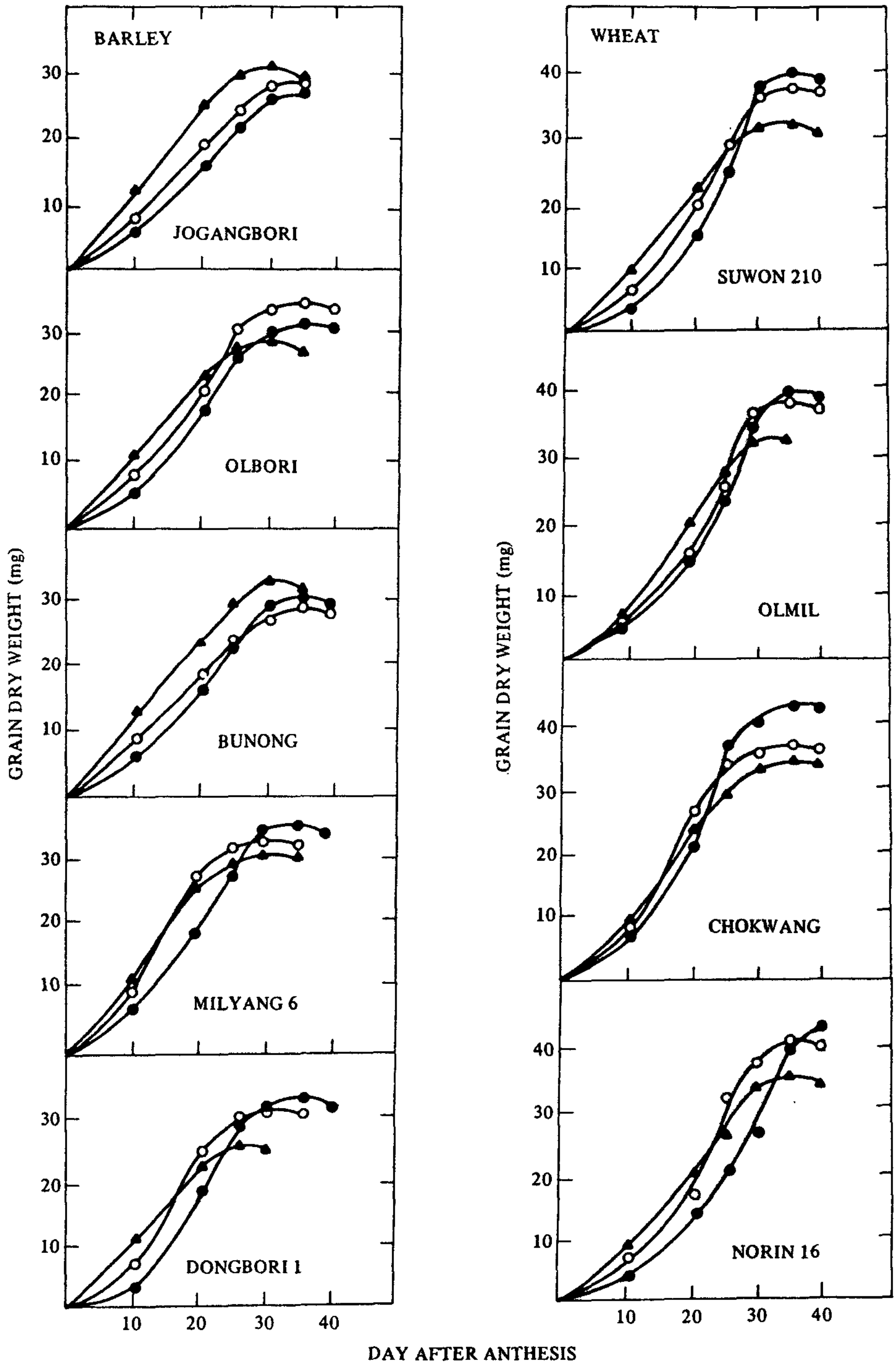

Fig. 3. Changes in grain weight with days after anthesis in relation to heading date. Symbols represent the treatments such as seeding on 13 Oct. + longday treatment(●), seeding on 13 Oct. + natural condition(○), and seeding on 30 Oct. + natural condition(▲).

Table 2. Changes in leaf area, LAD', NAR' related to heading time for wheat and barley.

Species	Varieties	Heading	Leaf area (cm^2 $culm^{-1}$)	LAD'[1)] (cm^2.day)	NAR'[2)] (mg·cm^{-2}.day^{-1})
Wheat	Suwon 210	April 30	61.0c	925bc	0.75c
		May 6	72.4b	1,056b	1.05b
		May 13	58.9c	489e	2.31a
	Olmil	April 30	61.5c	1,051b	0.94bc
		May 6	97.0a	1,345a	1.14bc
		May 15	63.0c	859c	1.78ab
	Chokwang	May 5	65.8bc	1,161ab	1.04be
		May 8	98.3a	1,092b	1.55ab
		May 16	70.0b	888c	1.99a
	Norin 16	May 2	52.3d	950bc	1.24b
		May 9	60.6c	776d	1.83ab
		May 14	55.1cd	620de	2.16a
Barley	Jogangbori	April 25	47.8e	708cd	1.55c
		April 29	56.5de	590d	2.45ab
		May 4	49.9e	482d	2.95a
	Milyang 6	April 25	60.0de	864bc	1.42cd
		May 2	76.2cd	957b	1.57c
		May 5	60.0de	615cd	2.61a
	Olbori	April 24	62.3de	927b	1.30cd
		May 2	68.4d	945b	1.71c
		May 6	61.0de	687cd	2.37ab
	Dongbori 1	April 26	89.7bc	897bc	1.37cd
		May 3	99.4ab	753c	1.94bc
		May 6	93.2bc	687cd	2.25abc
	Bunong	April 28	109.5a	1,439a	1.02d
		May 2	98.2ab	1,116b	1.62c
		May 10	112.0a	986b	1.94bc

1) Leaf area duration: integral of leaf area over time from 10 days after anthesis
2) Net assimilation rate was caculated from [grain dry weight] ÷ LAD'
The same letters in each row mean non-significant difference by LSD test at p=0.05 level.

and net assimilation rate (NAR) were illustrate in Table 2. Leaf area, which represents a good index fox source size of photosynthsis,[13)] was measured from 10 days after anthesis. Leaf senescence rapidly enhanced over time, especially in the plants headed late. The plants headed early sustained green leaves relatively longer period. For this reason, LAD of the plants headed either early or late was not greatly different, though the period of grain filling was longer in earlier heading. NAR, which takes account of the rate of photosynthesis per unit leaf area[9)], changed proportionally to heading time, but showed the same pattern among varieties. NAR and air temperature during the period of grain fill showed higher correlations as observed in other reports.[9,11)] In this respect, we concluded that although early heading could bring relatively longer period for green leaves, initial leaf area and NAR during the filling period will much reduce.

Number of spikes per plant and number of grains per spike were greatly reduced in early heading (Table 3). It seemed that the reduction of these traits had great influence on the grain yield. Thousand grain weight increased as heading was hastened. However, it was reversed in Jogangbori and Bunong as shown in Fig. 3.

Table 3. Variations in the yield components related to heading date for wheat and barley.

Crops	Varieties	Heading	No. of spikes/ plant	No. of grains/ spike	1,000 grain weight(g)	Fertility (%)
Wheat	Suwon 210	April 30	5	20	34.8	76.7**
		May 6	8	30	37.1	94.2
		May 13	3	34	33.1	–
	Olmil	April 30	5	26	38.1	67.2**
		May 6	7	43	35.6	93.6
		May 15	3	44	35.2	–
	Chokwang	May 5	5	27	44.7	68.9**
		May 8	7	43	38.5	99.2
		May 16	3	44	34.4	–
	Norin 16	May 2	5	27	42.0	76.8**
		May 9	8	50	40.5	98.1
		May 14	3	46	34.3	–
Barley	Jongangbori	April 25	5	28	26.8	85.5 NS
		April 29	10	35	28.4	98.5
		May 4	3	39	27.1	–
	Milyang 6	April 25	8	41	34.9	83.3*
		May 2	7	51	32.6	95.3
		May 5	4	50	30.8	–
	Olbori	April 24	4	38	31.8	91.3 NS
		May 2	6	48	33.7	95.0
		May 8	3	45	28.0	–
	Dongbori	April 26	4	38	32.4	86.1 NS
		May 3	7	48	30.4	91.3
		May 6	2	52	29.7	–
	Bunong	April 28	7	48	30.6	95.1 NS
		May 2	5	59	30.6	95.0
		May 10	3	57	33.4	–

*, **: Significant difference at p=0.05 and 0.01, respectively
NS means non-significant

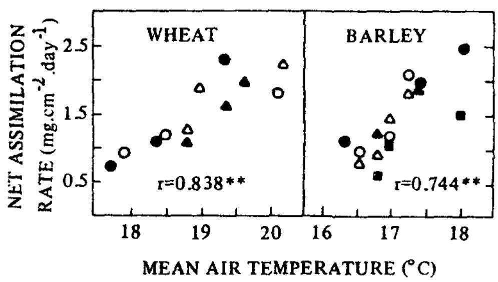

Fig. 4. Relationship between mean air temperature for the grain filling period and net assimilation rate. Symbols are the same as in Fig. 1.

Low fertility in the early-headed plants had to be a reason for the reduction in grain number for both wheat and barley. Toda[10] reported that continuance of low temperature ranging from 0°C to 4°C for 2 to 4 hours at heading time brought severe sterility in wheat. In this study the low fertility was presumably attributed to the daily lowest temperature ranged form 0°C to 5°C for 1 to 3 hours, April 20-25, 1979, around heading time of the early headed plants in wheat. However, it is still uncertain wheather the low fertility in this study was mainly caused by low temperature or not. This problem needs more detail and precise study under temperature-controlled environment.

In conclusion, hastening of heading earlier than present situation, May 5 to 10 for winter wheat and

May 1 to 5 for winter barley in Suwon, Korea. accompanies reduction of grain yield and less extent of green tissues. It seemed that it is very difficult to achieve early maturation by hastening of heading. In addition, the periods from heading to anthesis and from anthesis to maturity have to be considered for selection of earliness in wheat and barley, especially under low temperature condition.

摘　要

秋播 大·小麥의 早熟品種의 早期出穗에 따른 開花登熟 및 收量性 變化를 究明하고자 大麥品種 早強보리, 密陽6號, 올보리, 冬보리1號 및 富農과 小麥品種 水原210號, 올밀, 早光 및 農林16號 等을 供試圃場條件에서 播種期 差異와 長日處理로써 早期出穗 및 出穗期 差異를 誘導하여 本 實驗을 遂行하여 얻은 結果를 要約하면 다음과 같다.

1. 播種期 및 長日處理에 의해 大·小麥에서 15日의 出穗期 差異가 誘導되었으나, 成熟期는 불과 2~6밖에 促進되지 않았다.

2. 早期出穗한 경우 出穗~開花 日數 및 登熟日數가 延長되었으며, 出穗~開花 日數 延長이 더 큰 것으로 나타났고, 이들 期間과 平均氣溫 間에는 各各 高度의 負相關이 있었다.

3. 早期出穗한 것일수록 登熟初期의 葉面積은 좁았고, 葉面積維持期間(Leaf area duration)은 컸으며, 純同化率(NAR)은 낮았다.

4. 早期出穗한 것에서 千粒重은 增加하였으나 種實收量은 현저히 減少하였는데 이는 주로 穗數 및 一穗粒數의 減少에 起因하는 것으로 나타났다.

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