Plant Physiol. (1966) 41, 437-442

Effect of Gamma Radiation on the Ripening of Bartlett Pears[1]

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Revised manuscript received August 16, 1965.

Summary. Gamma radiation at doses of 300 Krad or more inhibits the ripening of Bartlett pears (*Pyrus communis* L.). Immediately after irradiation there is a transitory burst of C_2H_4, which subsequently declines in fruits subjected to inhibitory doses. Ethylene production associated with ripening begins at the same time in unirradiated fruits and those subjected to noninhibitory doses, but the latter produces much more C_2H_4 at the climacteric peak. Fruits subjected to inhibitory doses produce low levels of C_2H_4 unless subjected to exogenously applied C_2H_4, whereupon they produce enough of the gas to induce ripening in unirradiated fruits.

Pears subjected to 300 and 400 Krad of gamma rays did not ripen even when held in a flowing atmosphere containing 1000 ppm of C_2H_4 for 8 days at 20°. It is concluded that the action of gamma rays on Bartlett pears involves both an inhibition of C_2H_4 production and a decreased sensitivity of the fruit to the ripening action of the gas. Ripening of Bartlett pears is inhibited by gamma radiation only when applied to preclimacteric fruit.

Fruits of the Bartlett pear (*Pyrus communis* L.) exhibit a climacteric in rate of respiration and ethylene (C_2H_4) production as they ripen. The role of C_2H_4 in the ripening of fruits has received much attention (1, 2, 3, 4, 5, 18). There are 2 schools of thought on the role of C_2H_4, those who consider it a ripening hormone (5, 11, 15), and those who consider it a by-product of the ripening process (3). Despite a sizeable literature on the production of C_2H_4 by fruits and its effectiveness in stimulating ripening, its biosynthetic mechanisms and mode of action are not known (4).

In earlier studies of the effects of 8 mev electrons from a linear accelerator (17) on Bartlett pears, we noted an apparent retardation of ripening in mature but unripe specimens subjected to 200 kilorad (Krad) or more. The irradiated fruit showed a marked increase in rate of CO_2 production immediately after treatment. The respiratory rate remained high but the fruits did not develop the yellow color typical of ripe pears. We found that, immediately after treatment, irradiated pears evolved C_2H_4 at a higher rate than that of unirradiated fruit. The present work was done to evaluate the effects of gamma irradiation on the ripening of Bartlett pears.

Materials and Methods

Mature but unripe Bartlett pears were obtained from the University orchard at Davis, and commercial orchards near Walnut Grove and Placerville, California. The fruits were chilled to 0° for 5 to 7 days to ensure uniform ripening, then placed in the experiments. The fruits were carefully selected for uniformity of size and color and freedom from defects. Ten fruits per sample and 4 samples per treatment were used. Respiratory rates were measured by the method of Claypool and Keefer (6). Ethylene concentration in the airstream emerging from jars containing the fruits was measured by gas chromatography in an aerograph A-600B Hy-Fi flame ionization unit fitted with a 152 × 0.16 cm column packed with 60/80-mesh alumina. The identity of C_2H_4 was confirmed by treating samples of air emerging from the jars of fruit with mercuric perchlorate, brominated charcoal, and aqueous KOH (4, 16). Ethylene is removed by the first 2 systems but not by the latter. Ethylene trapped in the mercuric perchlorate was released by the method of Young et al. (23) and analyzed by gas chromatography.

Irradiation was done in the Mark II experimental food irradiator (19), with air passing over the fruits at 6 liters per minute to preclude depletion of O_2 and accumulation of CO_2 in the atmosphere. Air and fruit temperatures during irradiation were 20°. The dose rate in the irradiator was approximately 300 Krad per hour. Dosimetry was done as described by

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Romani et al. (20). The dose received by the fruit varied less than 11 %.

Ripening studies were conducted at 20° at a relative humidity of 93 %. Cold storage of fruits was at 0° at a relative humidity of approximately 90 %. Changes in the firmness of the flesh of the pears were measured with a Magness-Taylor pressure tester (10) fitted with a 8 mm tip.

Results

In our early studies the radiation source employed did not permit treatment of enough pears to allow evaluation of ripening changes other than the change from green to yellow skin color. This attribute is not a reliable index of ripening in pears grown in the Sacramento River delta. In some years these pears show only minor color changes associated with ripening. Thus, in this study, we first determined the effect of gamma rays on softening of the fruit in cold storage and under ideal ripening conditions of 20° and 93 % relative humidity. The changes in flesh firmness of irradiated pears during 60 days of storage at 0° are shown in figure 1A. There was an immediate softening of the fruit following irradiation. During the first 10 days in cold storage there was an additional decline in firmness; thereafter, firmness in all lots increased.

Figure 1B shows changes in firmness during the ripening of irradiated pears at 20° following 60 days of cold storage at 0°. Fruits subjected to 0, 100, and 200 Krad softened very rapidly, reaching an edible firmness within 4 days. After 9 days at 20°, fruits subjected to 300 and 400 Krad had still not softened enough to be edible. These lots never reached an acceptable yellow color, and although the firmness of the flesh declined to an acceptable value in 20 days, the flesh was mealy and atypical of ripe fruit of the variety. Similarly, the flavor of irradiated fruit was insipid and atypical.

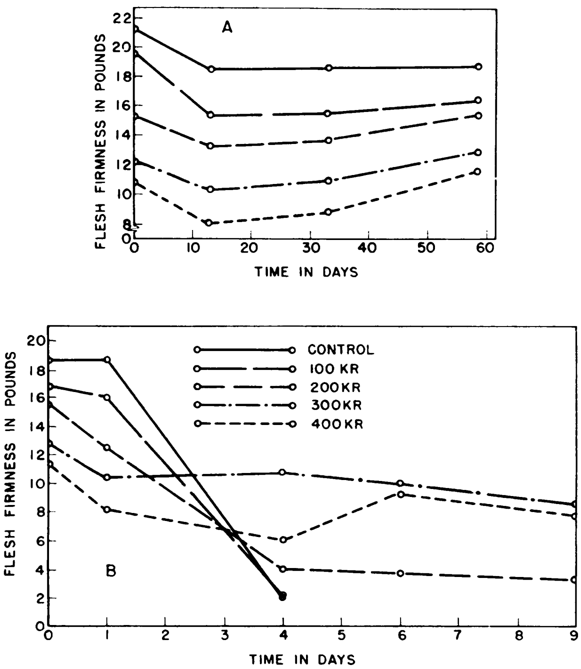

Fig. 1. Changes in flesh firmness of irradiated Bartlett pears. A) During 60 days at 0°. B) During ripening subsequent to cold storage.

Immediately after irradiation with 100 to 400 Krad of gamma rays, Bartlett pears evolve measurable quantities of C_2H_4 (fig 2). The rate of radiation-induced C_2H_4 production declined in all lots between the second and third days after treatment. By the third day after treatment the control fruit and those subjected to 100 and 200 Krad had begun to ripen, and their rate of C_2H_4 production increased as the fruits began the climacteric rise.

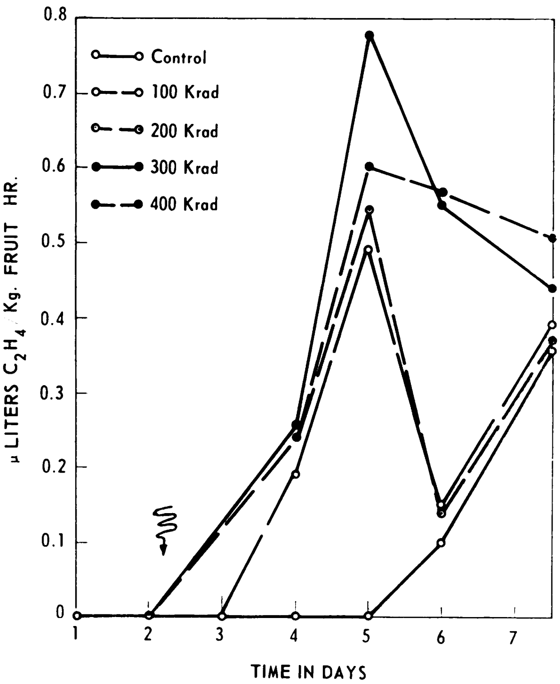

Fig. 2. Evolution of ethylene by Bartlett pears immediately after gamma irradiation.

Figure 3A shows the respiration rates of freshly harvested pears subjected to 0, 100, 200, 300 and 400 Krad after 5 days at 0°. There is an immediate increase in CO_2 evolution by fruits subjected to 100 Krad or more. Fruits subjected to 100 and 200 Krad showed a tendency to recover from the stimulus between the third and fourth days after treatment. By that time the climacteric rise had started, and these fruits proceeded through the climacteric maximum on the fifteenth day (12 days after treatment); about 3 days earlier than did the unirradiated control fruits. Fruits subjected to 300 to 400 Krad showed a high, erratic rate of respiration, and the climacteric maxi-

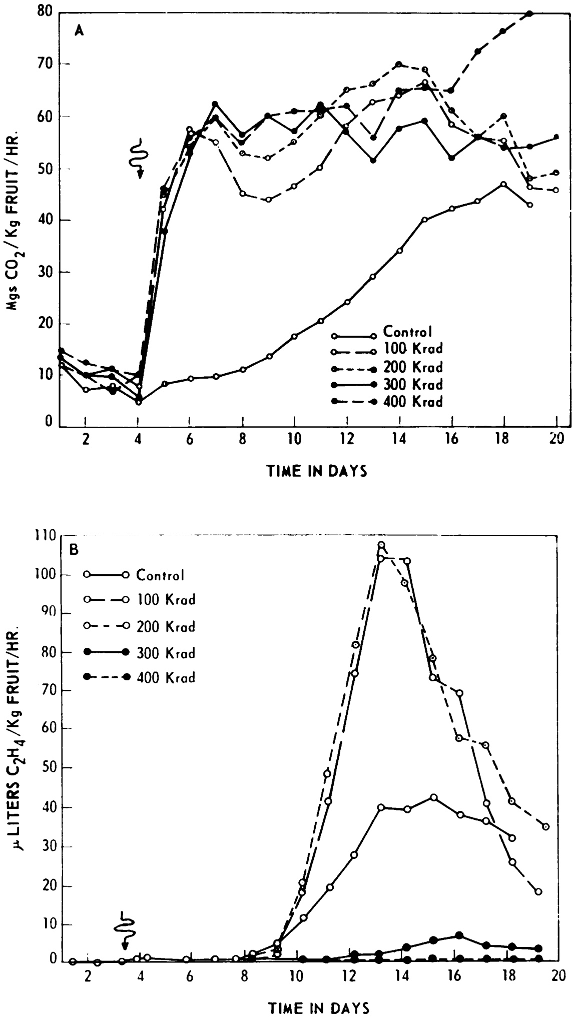

FIG. 3. Effect of gamma irradiation on Bartlett pears. A) Rate of CO_2 evolution. B) Rate of C_2H_4 evolution.

mum, if it occurred, was poorly defined. These fruits were still green in color when decay on their stems forced termination of the experiment, on the seventeenth day after irradiation. Rates of C_2H_4 production by the fruits are shown in figure 3B. The C_2H_4 production associated with ripening began at the same time for fruits subjected to 0, 100, and 200 Krad. The latter 2 lots showed a much higher rate of production at the climacteric maximum, which occurred on the thirteenth or fourteenth day, about 2 days earlier than for unirradiated control fruits. Ethylene production by pears subjected to 300 Krad increased slightly after the twelfth day of the experiment, but the fruits did not ripen normally as indicated by color changes and, finally, by taste. The C_2H_4 production by pears subjected to 400 Krad remained at a very low level throughout the experiment.

We wanted to know if gamma radiation could slow C_2H_4 production in fruits where the rate of production was already high. The fruits used were approaching the climacteric in respiration. Doses of 400 and 600 Krad reduced the rate of C_2H_4 production to a low level within 48 hours of treatment (fig 4). Doses of 200 Krad also lowered the rate, but the effect was somewhat less than that of the 2 higher doses.

Romani et al. (21) suggested that radiation-induced CO_2 evolution by Bartlett pears was markedly reduced if the treatment was made as the respiratory rate approached the climacteric peak. Therefore, an experiment was conducted to evaluate the effects of gamma radiation on pear fruits at several stages in the climacteric sequence. As shown in figure 5, the respiratory rate is stimulated in pears subjected to 300 Krad in the first half of the climacteric rise. Thereafter, little effect was noted. Fruits irradiated at any point prior to onset of the climacteric ripened slowly, if at all. No differences in rate of ripening were noted in fruits treated after the climacteric rise was well under way.

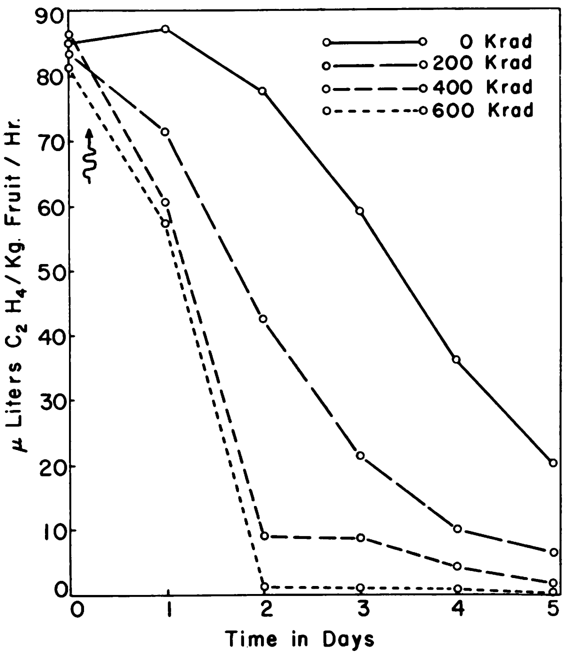

FIG. 4. Effect of gamma irradiation on the rate of C_2H_4 evolution by Bartlett pears irradiated near the climacteric peak.

Having shown that gamma radiation at doses of 250 Krad or more could inhibit the ripening of Bartlett pears, we next investigated whether treating irradiated pears with C_2H_4 could overcome the inhibition. The following treatments were made: 1) control; 2) 300 Krad on the second day, no C_2H_4; 3) 1000 ppm C_2H_4 for 48 hours on the first and second days; 4) 300 Krad on the second day followed by 1000 ppm C_2H_4 for 48 hours; and 5) 1000 ppm C_2H_4 on the first and second days followed by 300 Krad.

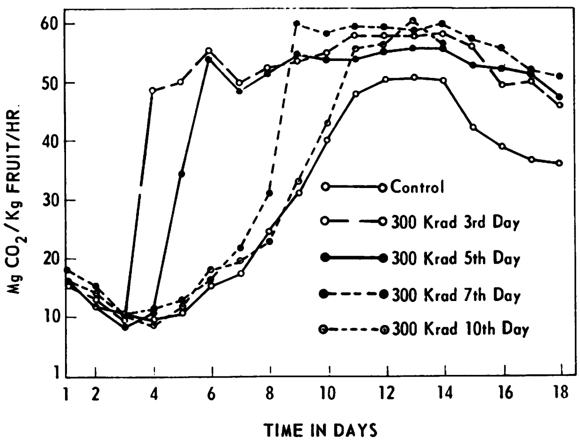

FIG. 5. Effect of gamma irradiation at various stages of the climacteric on the respiratory rates of Bartlett pears.

Air containing the C_2H_4 was applied in a continuous flow at a rate sufficient to maintain CO_2 concentration in the jars at less than 0.6 %. The magnitude of the response and the general pattern of radiation-induced CO_2 evolution were similar regardless of the C_2H_4 treatment (fig 6). Ethylene did not exert a clearly defined effect on the respiration rate of the irradiated pears. It is clear that 48 hours of exposure to 1000 ppm C_2H_4 was adequate to stimulate ripening in unirradiated pears. Irradiated fruit subjected to 300 Krad, however, failed to ripen normally when treated with C_2H_4 either before or after irradiation. The irradiated fruits were kept for 6 days after the control fruits were fully ripe. They never developed a full yellow color, although the green color was noticeably less intense; the fruits were not soft, and the flavor was insipid and atypical for the variety.

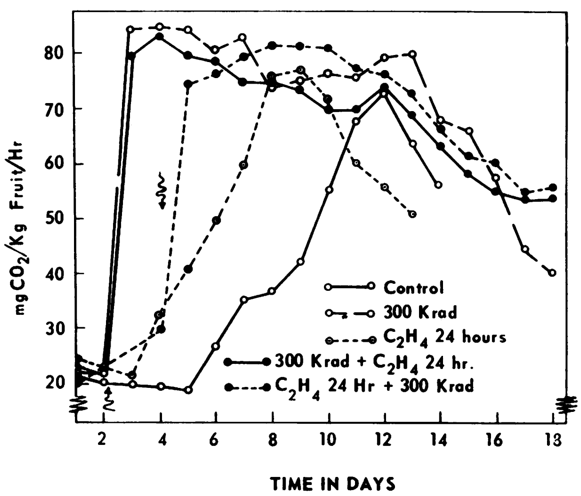

FIG. 6. Effect of 24-hour C_2H_4 treatments on irradiated and unirradiated Bartlett pears. Applications were in the order listed in dual treatments.

Bartlett pears subjected to 300 Krad still have the capacity to produce C_2H_4 in amounts that would normally cause unirradiated fruits to ripen (fig 7). Ethylene applied before or after irradiation stimulates the endogenous production of C_2H_4 by irradiated pears. Gassing before irradiation gives the greater stimulus. The data for respiration (fig 6) do not show a clear climacteric pattern for the irradiated fruit. However, as shown in figure 7, C_2H_4-treated, irradiated fruit clearly show a peak production of C_2H_4 resembling a climacteric, occurring 1 to 3 days after the peak in untreated fruit.

The fact that irradiated pears did not ripen normally when subjected to stimulatory amounts of C_2H_4, although producing sufficient amounts of the gas to induce ripening in untreated fruit, indicates that gamma radiation reduces the sensitivity of this

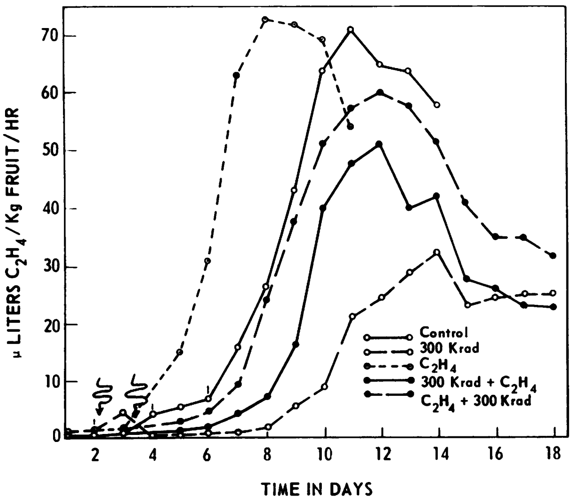

FIG. 7. Effect of gamma irradiation and C_2H_4 treatments on C_2H_4 production by Bartlett pears. Applications were in the order listed in dual treatments.

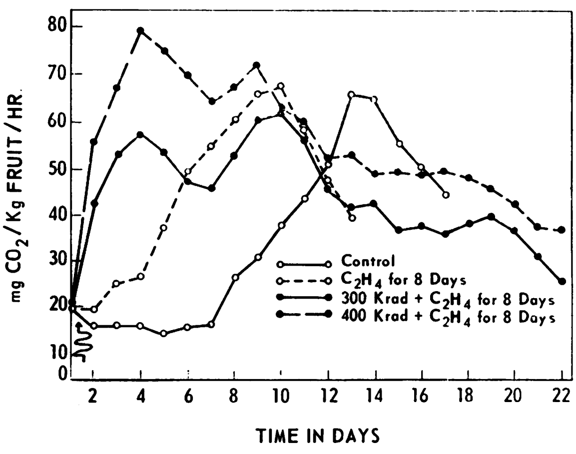

FIG. 8. Effect of gamma irradiation and long-term C_2H_4 treatments on the respiratory rate of Bartlett pears. Applications were in the order listed for dual treatments.

fruit to C_2H_4. Therefore, a series of experiments were conducted to ascertain the effect on irradiated pears of sustained treatment with C_2H_4 over several days' time. The following treatments were made: 1) control, no C_2H_4, no irradiation; 2) 1000 ppm C_2H_4 for 8 days beginning on the second day; 3) 300 Krad on the second day followed by 1000 ppm C_2H_4 for 8 days; and 4) 400 Krad on the second day followed by 1000 ppm C_2H_4 for 8 days. Figure 8 shows the effects of these treatments on the respiration rate of the fruit. There is an indication that both irradiated lots reached a climacteric peak at about the same time as unirradiated fruits subjected to 1000 ppm C_2H_4. The latter fruits were a full yellow color by the time of this peak, while the irradiated fruit showed only a slight loss in green color. The irradiated C_2H_4-treated lots were observed for 21 days after treatment. The fruits finally developed a fair amount of yellow color, but their texture was mealy and their flavor atypical of ripe pears.

Discussion

Two possible explanations may be offered for the burst of C_2H_4 evolved by pears shortly after irradiation. First, it may be induced by the physical injury to the fruit. Mechanical injury is known to induce C_2H_4 production in some tissues (4). While irradiated pears show no visual injury symptoms, they are physically damaged by gamma radiation as can be seen in figure 1A in the marked reduction in the firmness of the flesh. The nature of injury-induced C_2H_4 production by fruits is not known.

A second explanation may be production of C_2H_4 via radiolysis of alcohols, esters and other compounds in the fruit. Fresh Bartlett pears contain esters of ethyl, *n*-amyl, *n*-butyl, *n*-hexyl, and *n*-propyl alcohols (14). Bombardment of alcohols with helium ions produces traces of C_2H_4 (13). Irradiation of 50 ml of ethyl, *n*-propyl, and *n*-butyl alcohols to 100 Krad in our irradiator produced easily measurable quantities of C_2H_4. It is probable that gamma irradiation will produce C_2H_4 from many compounds found in fruit.

Pears have a sizeable volume of internal atmosphere containing 19 to 20 % O_2. Gamma irradiation of O_2 produces ozone. We have measured concentrations of ozone of about 1 ppm in air passing through the radiation field in our irradiator. Thus, it is expected that considerable quantities of ozone will be produced in the intercellular and intracellular spaces of pears during irradiation. Ozone reacts readily with olefins (7). However, when the rate of C_2H_4 evolution of 700-g samples of pears was measured during irradiation with air passing over the fruit at 185 ml per minute, doses of 0, 50, 100, 200, 400, and 600 Krad gave 0, 0.003, 0.004, 0.006, 0.008, 0.010, and 0.014 ppm, respectively. This indicates that gamma irradiation of pears stimulates C_2H_4 production to such an extent that the ozone in the irradiator cannot oxidize it before it is swept from the gamma field.

The data presented here show that gamma irradiation at doses of 300 Krad or more markedly reduces the sensitivity of Bartlett pears to the ripening action of C_2H_4 even though the fruits are held under conditions considered ideal for ripening. The sensitivity of fruits to C_2H_4 can be reduced by low temperatures (8), high temperatures (22), or atmospheres containing low percentages of O_2 (9). Fruits held under these conditions will ripen normally when placed in a favorable environment provided that the duration of the treatment is not excessive. Bartlett pears subjected to 300 Krad or more of gamma rays did not ripen normally even when held in 1000 ppm of C_2H_4 for 8 days at 20°, a relative humidity approaching saturation, and an atmosphere of about 21 % O_2 and 0.6 % or less of CO_2. One day under these conditions is adequate to cause ripening in unirradiated pears (fig 6).

From figure 3B, one might conclude that gamma rays at doses of 300 Krad or more inhibit ripening of pears by reducing their capacity to produce C_2H_4. That is not the case, though, for, as shown in figure 7, pears subjected to inhibitory levels of radiation will produce C_2H_4 in amounts adequate to cause ripening if they are subjected to 1000 ppm of the gas for 24 hours immediately before or after irradiation. Despite this production of C_2H_4, they did not ripen normally.

Degree of ripeness at irradiation can affect the response of Bartlett pears to gamma radiation. As noted above, preclimacteric fruits subjected to 1000 ppm of C_2H_4 just before or after irradiation failed to ripen normally. However, when pears have ripened enough to be about one-half way through the ascending portion of the climacteric, gamma irradiation does not inhibit their ripening, which indicates that the ripening process has a stage beyond which it is insensitive to gamma radiation.

Whether irradiated preclimacteric pears would ever ripen normally is difficult to evaluate. The softening effect of gamma rays during irradiation is profound and the tissues do not develop the smooth, juicy texture characteristic of the Bartlett pear before physiological disorders and subsequent decay destroy the fruits.

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