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Regulation of apical dominance through pinching and its effect on vegetative growth and floral yield in African marigold (*Tagetes erecta* L.)

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Abstract
Marigold (Tagetes erecta L.) is a widely cultivated ornamental crop valued for its bright and attractive flowers, which hold significant importance in decoration, religious rituals, and the floriculture trade. Pinching, a cultural practice involving the removal of the terminal bud, is an effective method for modifying plant growth, improving branching, and enhancing flower production. This review compiles existing research on the role of pinching in influencing vegetative development, flowering behavior, floral quality, and overall yield in African marigold. Pinching disrupts apical dominance, promotes axillary bud outgrowth, increases branching, and redirects assimilates towards lateral shoots, ultimately improving flower production. Pinching significantly improves flower yield plant^{-1} and hectare^{-1}, with notable gains in total flower count and yield quality. However, unpinched plants exhibit larger individual flowers with prolonged longevity. Seasonal timing, cultivar differences, and environmental conditions modulate pinching outcomes. The integration of pinching with cultivar-specific and seasonal management practices offers a low-cost, effective agronomic strategy for optimizing marigold productivity and market value.

Keywords: Marigold (*Tagetes erecta*), pinching, single pinching, double pinching, vegetative growth, flower

Introduction
Marigold (Tagetes erecta L.), a member of the Asteraceae family, is one of the most important ornamental flowers grown worldwide and contributes significantly to the loose flower market (Jyothi *et al*., 2018) [45]. Native to Mexico (Singh *et al.*, 2019) [41], marigolds have been cultivated since ancient times and continue to hold strong cultural and traditional value. They are commonly used in landscaping, home gardens, pots, and as part of herbaceous borders (Singh *et al.*, 2017) [42]. In different cultures, marigolds carry symbolic meanings known as “Sayapatri” in Nepali and “Gainda” in Hindi. Among the many species of Tagetes, African marigold (*T. erecta*) and French marigold (*T. patula*) are the most widely grown due to their ornamental appeal (Rayberg, 1915). Through hybridization between these two species (*T. erecta,* 2n=24 and *T. patula,* 2n=48), three main horticultural groups have been developed: African, French, and Triploid marigolds (Dhakal, 2016) [7]. Another species, *Tagetes minuta,* is valued primarily for its essential oil content.
T. erecta exhibits a tall growth habit, reaching heights between 0.1 and 2.2 meters, characterized by extensive branching and a profusion of flowers in various shades of yellow and orange (Singh *et al.*, 2019) [41]. While adaptable to diverse soil conditions, optimal growth is observed in well-drained soils. Marigolds are highly popular because they are easy to grow, adapt well to different conditions, flower quickly after planting, and produce an abundance of blooms over a long period. Their natural resistance to many pests and their vibrant appearance further add to their appeal (Jyothi *et al*., 2018) [45]. Marigold play a crucial role in cultural practices, serving as essential components of floral offerings in religious ceremonies, decorative wreaths, and floral arrangements. Moreover, they represent a valuable source of natural products with applications in food production, natural colorants, and pigments, particularly xanthophylls (Jyothi *et al.*, 2018) [45].

In an effort to enhance floral yield, horticultural practices such as pinching are employed. Pinching, the removal of the apical bud, is a critical technique for manipulating plant architecture and optimizing flower production. By removing the apical bud, plant energy is redirected towards the development of lateral branches, leading to an increase in the number of flowering shoots and consequently, a higher floral yield (Singh *et al.*, 2019) [41]. While pinching may temporarily delay flowering, it ultimately results in a greater abundance of blooms. Research findings indicate that delayed pinching can maximize the number of branches and overall flower yield in marigold (Sehrawat *et al*., 2003) [35]. This results in a more compact and bushy plant architecture with a higher number of flowering branches, ultimately leading to increased flower yield and improved overall plant performance (B.C. *et al.,* 2020). The removal of the apical bud also influences the hormonal balance within the plant. This hormonal regulation plays a crucial role in optimizing growth and development, contributing to enhanced yield parameters (El-Shayeb *et al.*, 2021) [8].

Effect of pinching in growth

Pinching has a significant influence on the vegetative growth parameters of marigold, particularly plant height. Several researchers have reported that pinching reduces plant height while promoting lateral branching and increased plant spread. This is primarily due to the suppression of apical dominance, which is governed by auxins in the shoot apex. Patil and Kale (1991) [23] first documented that pinching markedly reduced plant height in marigold. They observed that pinching before flower bud initiation led to increased plant spread, whereas pinching at the time of flower bud emergence resulted in a higher number of lateral shoots.

Non-pinched plants tend to achieve greater final height due to uninterrupted apical dominance, as noted by Sunita *et al.* (2007) [43], Rajyalakshmi and Rajashekhar (2014) [29] and Gnyandev *et al*. (2014) [9]. In contrast, pinching was found to significantly reduce the plant height, while simultaneously increasing the plant spread and number of branches.

Kumar *et al.* (2012) [13], Rathore *et al*. (2011) [31], and Maharnor *et al*. (2012) [15] observed that plants pinched at 30 days after transplanting (DAT) attained greater height than those pinched at 40 or 50 DAT. In contrast, Bhat and Shepherd reported that single pinching at 35 DAT reduced plant height compared to both double pinching and non-pinched plants. Similarly, Khandelwal *et al.* (2003) [11] found that early pinching at 20 DAT lowered plant height, with an average of 72.82 cm.On the contrary, Badge *et al.* (2018) [4] observed maximum height increase in plants pinched at 15 DAT, whereas minimum height was recorded in non-pinched plants of *T. erecta*, suggesting varietal and environmental influences.

Physiologically, the removal of the terminal bud during pinching induces temporary stress in the plant, requiring time for recovery, thereby impeding vertical growth. A study conducted on *T. erecta* cv. 'Pusa Narangi Gainda' by Shrivastava *et al*. (2002) [40] confirmed that pinching at 20 DAT significantly reduced plant height, while pinching at 30 and 40 DAT improved the number of secondary branches.

In summary, strategic timing of pinching plays a crucial role in regulating the height of marigold plants. While early pinching may moderately restrict vertical growth, it effectively promotes branching and plant spread—traits desirable for maximizing floral yield and uniformity in marigold cultivation. Pinching significantly enhances the number of branches in marigold by disrupting apical dominance and promoting the activation of axillary buds. The redirection of growth hormones, especially auxins, away from the apical meristem promotes lateral branching and greater canopy spread (Sasikumar *et al.*, 2015) [34].

Branching in marigold and related ornamentals is strongly influenced by the timing of pinching. In China aster cv. 'Phule Ganesh', Gnyandev *et al.* (2014) [9] reported that pinching at 15 days after transplanting (DAT) produced the highest number of branches compared to non-pinched plants. In African marigold (*Tagetes erecta*), Sarkar *et al.* (2018) [33] found that pinching at 40 DAT resulted in the maximum number of branches (40.55 branches/plant), suggesting that later pinching promotes stronger lateral growth. Similar findings were reported by Singh *et al.* (2019) [41] and Kumar *et al.* (2012) [13], where pinching at 40 DAT significantly increased the number of primary branches and leaves per plant. However, branching response also varies with developmental stage. Sharma *et al.* (2006) [39] observed that pinching at 20 DAT produced the highest number of secondary branches. In African marigold cv. 'Pusa Basanti Gainda', Rajbeer *et al*. (2009) [28] noted that a single pinching at 30 DAT encouraged more secondary branches than pinching at 40 DAT or leaving plants unpinched.

Early research by Singh and Arora (1980) indicated that pinching at 40 days after transplanting (DAT) promoted greater branching, whereas earlier pinching at 20 DAT reduced it. In contrast, Sekhan (1981) [36] observed that pinching at 30 DAT in African Giant Double Orange marigold caused notable reductions in plant height, fresh weight, and number of branches compared to pinching at 20 or 40 DAT, highlighting the possible role of varietal and environmental interactions. More recent studies also support the benefits of later pinching. For instance, reported that double pinching at 50 DAT significantly increased the number of branches (21.50) compared to unpinched plants.

Effect of Pinching on Flowering

Pinching significantly influences the phenology of flowering in marigold, particularly by delaying the onset of first flowering and 50% flowering. This delay is primarily attributed to the temporary redirection of plant energy toward vegetative recovery and branching after the apical meristem is removed, which postpones the plant's entry into the reproductive phase.

Meena *et al*. (2015) [16] conducted an experiment with three different pinching treatments no pinching, single pinching at 30 DAT, and double pinching at 30 & 60 DAT on Marigold. Their findings showed that double pinching significantly delayed flowering to 94.85 days, followed by single pinching (77.12 days) and no pinching (71.35 days). Similar trends were observed in the cultivar 'Pusa Narangi Gainda', supporting these results (Pushkar and Singh, 2012) [27]. In another study on African marigold cv. 'Sirakole', Parhi *et al*. (2015) [17] observed that double pinching at 30 and 45 DAT delayed flowering to 59.50 days, while single pinching at 30 DAT resulted in 52.50 days, and the earliest flowering (48.33 days) occurred in un-pinched plants.

External environmental factors also play a crucial role in flowering time. Meena *et al.* (2015) [16] noted that the planting date significantly impacted days to first flowering, with 15 September plantings flowering earliest (66.70 days) and 15 November plantings flowering latest (97.71 days), likely due to declining temperature and light intensity affecting plant growth. Regarding 50% flowering, studies report a relatively mild effect from pinching. Khan *et al*. and Sehrawat *et al*. (2003) [35] reported that pinched plants took longer (54.99 days) to reach 50% flowering compared to no pinched plants (50.56 days). This minor delay is attributed to the extra time required for new lateral branches to mature and initiate floral development.

Double pinching consistently delays flowering due to energy diversion to vegetative recovery. Single pinching causes moderate delays, while no pinching leads to earliest flowering. Environmental conditions like planting time, temperature, and nutrient status significantly modify the flowering response.50% flowering is only slightly affected by pinching, with a delay of approximately 4-5 days observed in most studies.

Effect of Pinching on Quality Parameters and Flower Yield

Pinching is a vital cultural practice in floriculture aimed at enhancing plant architecture and optimizing yield and quality. In *Tagetes erecta L.*, pinching has demonstrated significant effects on flowering time, flower size, weight, stalk length, and longevity.

Arora and Khanna (1986) [2] reported that pinching delayed flower production by 10-12 days under the agro-climatic conditions of Ludhiana, India. Such delay can be strategically used to avoid market surplus. However, Singh and Puskar (2012) noticed that the longer flowering duration occurred when pinching was conducted at 30 days after transplanting (DAT). Contrarily, Prakash *et al*. (2016) [26] observed that no pinching resulted in the maximum flowering duration in African marigold cultivars 'Pusa Narangi Gainda' and 'Pusa Basanti Gainda,' findings further supported by Sehrawat *et al.* (2003) [35].

Regarding flower diameter, the results are varied. Patade *et al*. (2020) [22] reported that pinching at five weeks post-transplanting produced highest flower diameter, whereas indicated a reduction in diameter in pinched plants, attributing this to resource diversion toward vegetative growth. Srivastava *et al.* (2002) [46] and Khandelwal *et al.* (2003) [11] reported that unpinched plants of 'Pusa Narangi Gainda' yielded larger flowers (6.34 cm) and longer flower longevity (19.39 days) compared to pinched ones.

Naik *et al*. (2004) [18] noticed that unpinched plants produced highest flower diameter (8.12 cm) as compared to those pinched at 40 DAT (7.82 cm). Similarly, Kumar *et al*. reported that pinching at 28 DAT produced the longest stalk length and largest flower diameter in African marigold cv. 'Double Orange.' Fresh (7.64 g) and dry weights (5.16 g) of flowers were also highest in unpinched plants (Rathore *et al*., 2011) [31], a trend confirmed by Khobragade *et al.* (2012) [12].

Interestingly, Mahanor *et al.* (2011) observed maximum stalk length in control plants and longer flower longevity in plants pinched at 30 DAT. Badge *et al.* (2018) [4] echoed these findings, reporting greater flower diameter and pedicel length in unpinched plants. In contrast, Nain (2017) [19] found that stalk length and fresh flower weight per plant (358.79 g) were significantly higher in plants pinched at 28 DAT. Baskaran and Abirami (2017) [47] further stated that double pinching improved flower size (6.18 cm) and individual flower weight (7.08 g).According to Palekar *et al*., flower weight, petal count per flower, and longevity were highest with no pinching and the application of 125 kg N/ha. Pinching at 28 DAT led to maximum stalk length and flower weight (Kundu *et al*., 2019) [14], while Pandey *et al*. (2021) [20] found that non-pinched plants of cv. 'Quality Kolkata Local' had the largest flower diameter (4.29 cm) and greatest fresh weight (4.32 g).

Seasonal timing also affects flowering. Mohanty *et al.* (2015) [17] reported that November planting resulted in higher flower counts. Baskaran and Abirami (2017) [47] observed that double pinching not only increased flower count but also improved flower size and longevity. Dali *et al*. (2019) emphasized that pinching diverts energy from vegetative to reproductive growth, boosting flower yield. Kalaimani *et al*. (2017) [10] reported 67.14 blooms per plant with optimal spacing and pinching, attributing this to enhanced lateral shoot development and increased carbohydrate accumulation during the reproductive phase.

Effect of Pinching on Flower Yield

The number of flowers per plant is a key trait for assessing productivity and yield in marigold. In cv. Orange Double, pinched plants produced more flowers (61.9) compared to non-pinched ones (50.6), with reports suggesting that double pinching can nearly triple flower numbers relative to unpinched plants (Sunitha *et al.*, 2007; Rajyalakshmi & Rajashikhar, 2014; Prakash *et al.*, 2016; Khan *et al.*, 2018) [43, 29,. 26, 11]. In Pusa Narangi Gainda, Meena *et al*. (2015) [16] recorded the highest flower count (34.91 per plant) with double pinching at 30 DAT, followed by single pinching (31.97) and no pinching (28.90). Similarly, Bhat and Shepherd (2007) [48] found that double pinching maximized flower production (63.81) compared to single pinching in the same cultivar. Tomar *et al*. (2004) [44] also reported that African marigold plants produced the highest flower number under double pinching (48.34), followed by single pinching (32.86) and unpinched plants (17.63). On the other hand, Parhi *et al*. (2016) [21] observed a slightly different trend in cv. Sirakole, where single pinching at 30 DAT yielded the maximum flowers (39.34), followed by double pinching at 30 and 45 DAT (38.16) and no pinching (34.50). Sarkar *et al*. (2018) [33] further noted that pinching at 40 DAT produced the highest flower count (62.78 per plant).

Singh and Arora (1986) [2] reported that in marigold (*Tagetes erecta*) cv. African Giant Double Orange, flower yield per plant was highest when pinching was done at 40 DAT. Similarly, Srivastava *et al.* (2002) [46] observed that pinching at 40 DAT produced the maximum number of flowers per plant (58.18) along with the highest yield (30.99 t/ha), compared to non-pinched plants which recorded only 42.80 flowers and 22.40 t/ha. Sehrawat *et al*. (2003) [35] reported that in African marigold cv. African Double Orange, pinching at 30 DAT produced the highest number of flowers per plant and maximum flower yield. Similarly, Tomar *et al*. (2004) [44] found that double pinching significantly increased flower number per plant (48.34), followed by single pinching (32.86), while unpinched plants recorded only 17.63 flowers. Naik *et al*. (2004) [18] also observed that pinching at 40 DAT resulted in the maximum flower yield (16.44 t/ha) compared to unpinched plants. In

cv. Pusa Narangi Gainda, Chauhan *et al*. (2016) [5] reported that pinching at 30 DAT increased the number of flowers (19.76 per plant) and flower yield (1700.78 g/m²) compared to control (17.60 flowers and 1120.53 g/m²). Shrivastava *et al.* (2002) [40] studied the effect of pinching at 20, 30, and 40 DAT in cv. Pusa Basanti Gainda and found that pinching at 40 DAT delayed flowering but improved flower number and quality compared to no pinching and earlier pinching intervals. Likewise, Sharma *et al*. (2006) [39] recorded the maximum flower number per plant (19.51), yield per plant (157.60 g), and yield per hectare (131.48 q/ha) when plants were pinched at 40 DAT, as compared to early pinching at 20 DAT in cv. Pusa Narangi Gainda. Manoj Kumar (2012) [13] further noted that in cv. Double Orange, plants pinched at 28 DAT produced the maximum number of flowers, along with the highest flower and seed yield per plant, compared to pinching at 7, 14, 21, or 35 DAT. Taken together, these studies suggest that the optimum time for pinching in African marigold generally falls between 28-40 DAT, although varietal differences do exist. The main reason is that pinching during this window balances vegetative and reproductive growth: removing the apical bud reduces apical dominance, encourages lateral branching, and increases the sites available for flower initiation. Early pinching (before 20 DAT) tends to reduce vigor and branching potential, while very late pinching (after 45 DAT) may delay flowering excessively and reduce yield. Thus, timely pinching enhances flower number, size, and overall yield by optimizing the plant's architecture and assimilate partitioning.

Several studies confirm that pinching enhances flower number and yield in African marigold. Bhat and Shepherd (2007) [48] observed that double pinching in cv. Pusa Narangi Gainda produced more flowers (63.81) and larger blooms (5.05 cm) than single pinching. Sunitha *et al.* (2007) [43] also noted a higher flower count in cv. Orange Double under pinching (61.9) compared to no pinching (50.6). In cv. Pusa Basanti Gainda, Rajbeer *et al.* (2009) [28] reported maximum flowers (18.64) when pinched at 40 DAT. Similarly, Rathore *et al*. (2011) [31] found that pinching increased both flower number (82.14) and yield (96.78 q/ha) compared to control. Maharnor *et al*. (2012) [15] also recorded higher flower number and yield at 30 DAT in cv. Double Orange.

According to Khobragade *et al*. (2012) [12], the pinched plant had the highest number of flowers (55.52) and the highest flower yield (334.70 g) compared to the unpinched plant (39.47 and 266.91 g, respectively). Pushkar and Singh (2012) [27] noted that the maximum number of flowers per plant was recorded with pinching 20 days after transplanting, and the highest flower yield (203.00 q/ha) was obtained with pinching of terminal shoots at 30 days after transplanting in African marigold compared to no pinching. Sharma *et al.*, (2006) [48] and Badge *et al*. (2018) [4] observed that at 15 DAT, pinching produced a maximum of 31.10 and 34.10 flowers per plant, respectively, compared to no pinching, which produced 24.35 and 25.01 flowers, respectively. Meena *et al*. (2015) [16] noticed that double pinching produced the most flowers per plant (34.91), followed by single pinching (31.97) and no pinching (28.90) at 30- and 60-days following transplanting. In comparison to no pinching, Mohanty *et al*. (2015) [17] found out that shoot pinching 30 days after planting significantly improved the weight of flowers per plot (3745.95 g), flower yield per hectare (13873.0 kg), number (173.01), and weight (0.25 g) of seeds per head, as well as seed yield (309.7 kg) per hectare.

Research consistently shows that pinching increases flower number and yield in African marigold. Parhi *et al.* (2015) [17] found that cv. Sirakole produced the highest flower number under pinching. Nain *et al.* (2017) [19] reported that pinching at 28 DAT gave the maximum flowers per plant (54.54), flower yield per plant (403.68 g), and yield per hectare (33.33 t). In cv. Pusa Narangi Gainda, Baskaran and Abirami (2017) [47] showed that double pinching produced more flowers (56.6), larger blooms (6.18 cm), higher yield per plant (347.8 g), and greater seed output (20.23 g), with nearly three times the yield of unpinched plants. Similarly, Sarkar *et al*. (2018) observed that pinching at 40 DAT resulted in the maximum flowers per plant (62.78) and yield (10.20 t/ha), while Singh *et al.* (2012) [27] recorded the highest yield (224.10 q/ha) with pinching at 30 DAT.

The most important variable in determining out the total number of flowers produced is the yield per plant. When compared to not pinching (226.91 g), pinching enhances flower yield per plant (334.70 g). According to Rathore *et al*. (2011) [13] and Kobragade *et al*. (2012), pinching enhances flower yield (96.78 q/ha) in comparison to non-pinching (68.78 q/ha). According to Srivastava *et al*. (2002) [46], other researchers also found that pinching the African marigold cv. Pusa Narangi Gainda after 40 days after transplanting produced the highest flower yield (30.99 tons/ha) as opposed to no pinching (42.80 and 22.40 tons/ha, respectively).

Yield per plant is a key indicator of overall flower production, and several studies confirm that pinching significantly improves it. For example, pinched plants recorded a maximum yield of 334.70 g per plant compared to 226.91 g in unpinched plants, while yield per hectare also increased (96.78 q/ha vs. 68.78 q/ha) as reported by Rathore *et al*. (2011) and Kobragade *et al.* (2012). Srivastava *et al.* (2002) [46] found that in African marigold cv. Pusa Narangi Gainda, pinching at 40 DAT produced the highest yield (30.99 t/ha) compared to non-pinched plants (22.40 t/ha). Similarly, Naik *et al.* (2004) [18] and Shrivastava *et al*. (2005) observed higher flower yield in cv. Pusa Basanti Gainda when pinched at 40 DAT (16.44 t/ha) compared to unpinched plants. Chauhan *et al*. (2005) also reported that pinching at 30 DAT gave the maximum yield (1700.78 g/m²) compared to control (1120.53 g/m²).

Conclusion

Pinching is a vital cultural practice in the cultivation of African marigold (*Tagetes erecta L.*), significantly influencing vegetative growth, flowering behavior, and overall yield. The removal of the apical bud suppresses apical dominance and promotes lateral branching, thereby increasing the number of flowering sites. Optimal results are often observed with single pinching at 25-30 DAT, which balances vegetative vigor, flowering duration, and marketable flower quality. While pinching may delay the onset of flowering, this is offset by an increase in the number of flowers per plant. Double pinching (at 30 and 45 DAT) further improves flower number and duration, though it may slightly reduce individual flower size and also found that double pinching increase flower per plant three times than non-pinching in marigold. In contrast, unpinched plants typically produce larger, heavier flowers with greater longevity but reduced total yield. The response to pinching

is also influenced by cultivar characteristics, planting season, and environmental conditions. For instance, November planting has been associated with increased flower production for winter season. Therefore, strategic timing and cultivar-specific management are essential for maximizing both flower quantity and quality. Pinching, when applied judiciously, serves as an effective agronomic strategy for improving commercial marigold production.

Table 1: Effect of Pinching Time on Growth Attributes of Marigold (*Tagetes* spp.)

Pinching Time (DAT)	Plant Height (cm)	Primary Branches	Secondary Branches	Reference
15	78.00	10	20	Badge *et al*. (2014)
20	72.82	13	25	Khandelwal *et al.* (2003) [11]
30	80.00	15	30	Kumar *et al*. (2012) [13]
35	75.00	14	28	Bhat and Shepherd (2007) [48]
40	70.00	16	35	Rathore *et al.* (2011) [31]
50	68.00	14	30	Maharnor *et al.* (2011)
No Pinching	89.00	8	15	Sunita *et al.* (2007) [43]

Table 2: Effect of Pinching on Days to First Flowering in Marigold

Pinching Treatment	Cultivar	Days to First Flowering	Reference
Single Pinching @ 30 DAT	*T. erecta*	77.12	Meena *et al*. (2015) [16]
Double Pinching @ 30 & 60 DAT	*T. erecta*	94.85	Meena *et al*. (2015) [16]
No Pinching	African marigold cv Sirakole	48.33	Parhi *et al.* (2016) [21]
Single Pinching @ 30 DAT	African marigold cv Sirakole	52.50	Parhi *et al.* (2016) [21]
Double Pinching @ 30 & 45 DAT	African marigold cv Sirakole	59.50	Parhi *et al.* (2016) [21]

Table 3: Summary of Pinching Effects on Quality Traits of *Tagetes erecta*

Trait	Best Treatment	Value/Result	Reference
Flower Diameter	No pinching	8.12 cm	Naik *et al*. (2004) [18]
	Double Pinching	6.18 cm	Baskaran & Abirami (2017) [47]
Fresh Weight	No pinching	8.93 g	Nain (2017) [19]
	Double Pinching	7.08 g	Baskaran & Abirami (2017) [47]
Dry Weight	No pinching	5.16 g	Rathore *et al.* (2011) [31]
Stalk Length	Pinching @28 DAT	4.90 cm	Khobragade *et al.* (2012) [12]
No.of Flowers/Plant	Double pinching	>31.80	Kalaimani *et al.* (2017) [10]
Flowering Duration	No pinching / 30 DAT pinching	Longer duration	Singh & Puskar (2012); Prakash *et al*. (2016) [27, 26]
Delayed Flowering	Pinching	10-12 days delay	Arora & Khanna (1986) [2]

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