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AGRONOMY

Harvest-Aid Interactions under Different Temperature Regimes in Field-Grown Cotton

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INTERPRETIVE SUMMARY

The purpose of this research was to determine the interactive effects of defoliants and a boll opener on defoliation, boll opening, and yield of early and late-planted cotton, and to relate these effects to the temperature regimes prevalent during and after harvest-aid application. We looked for possible interactions of three defoliants, tribufos (Folex®), thidiazuron (Dropp®), and dimethipin (Harvade®), with the boll opener, ethephon (Prep™)[1].

When preparing the crop for harvest, different harvest-aid chemicals are frequently tank-mixed to increase the likelihood of a favorable response, or optimize activity and reduce costs. Relatively little is known, however, about possible interactions between different types of harvest aids in field-grown cotton. Ethephon (Prep™ and similar products) may interact with various defoliants in cotton because of differences in mode of action or optimal temperatures for activity. Field temperatures during and after harvest-aid application are unpredictable, but later plantings are more likely to encounter cooler ambient temperatures than earlier plantings. Along the northern edge of the U.S. Cotton Belt, cool ambient temperatures are more likely to prevail during defoliation of late-planted cotton than in earlier plantings. Therefore, we planted 'DPL50' cotton in late April and mid-May for 3 years at the West Tennessee Experiment Station to study harvest-aid responses under different temperature regimes for defoliation.

Harvest aids were applied at 53 ± 5% open bolls. Air temperatures at the time of application ranged from 26 to 29°C (79 to 84°F) in early planted cotton, and from 19 to 24°C (67 to 76°F) in the later plantings. Average daily minimum temperatures during the first 3 days after treatment ranged from 16 to 20°C (60 to 68°F) in the earlier plantings, and from 10 to 16°C (50 to 60°F) in the later plantings. Different planting dates therefore resulted in relatively warm and cool temperature regimes.

Tribufos or dimethipin applied alone consistently increased defoliation in either warm or cool conditions, relative to untreated cotton. Thidiazuron, however, was less consistent when applied alone. In the early planted 1994 cotton and in two later plantings, thidiazuron did not increase defoliation relative to untreated cotton. Ethephon enhanced defoliation under warm or cool conditions, but interactions indicate that response to ethephon differed according to the defoliant used. Under very warm conditions, ethephon did not increase the defoliation by tribufos or thidiazuron, but it increased defoliation by dimethipin or by itself. In two tests under cooler conditions, ethephon enhanced defoliation by itself or with thidiazuron more than with tribufos or dimethipin. However, these latter defoliants were more effective than thidiazuron under cooler conditions.

The three defoliants used in this study did not directly influence boll opening under warm conditions. Under cooler conditions in 1996, however, there was less boll opening with dimethipin than with other defoliants or in untreated cotton. Under warmer conditions, ethephon increased boll opening except when it was applied with tribufos in 1995 and 1996. Under cooler conditions, ethephon required more than 7 days to significantly increase boll opening. Under these conditions, ethephon did not increase boll opening when it was applied with dimethipin, and it had inconsistent effects with other defoliants.

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[1]Trade names of harvest aids are mentioned here only to specify materials applied in this research. Mention of these trade names does not constitute commercial endorsement, nor does it imply disapproval of similar product not mentioned.

Lint yields at first harvest showed similar trends as boll opening. Ethephon increased first-harvest yields by 10 to 20% in all temperature regimes except one. The yield response to ethephon was not significantly different from controls under very warm conditions in 1996. Defoliants did not significantly influence lint yield at first harvest in early or late plantings. Weak ethephon-defoliant interactions were attributable to reductions in ethephon response by defoliants, similar to boll opening. Total lint yields were not affected by defoliants, but ethephon significantly increased total yields in two tests under cooler conditions. However, ethephon decreased yield slightly in one early planted experiment in which bolls opened under very warm conditions.

These experiments revealed several ethephon-defoliant interactions that are influenced by temperature. Under cooler conditions, ethephon enhanced defoliation with thidiazuron more than with other defoliants. However, either tribufos or dimethipin was more effective as a defoliant under these conditions. The most effective combination for cool-weather defoliation was tribufos and ethephon. However, this combination was relatively ineffective in enhancing boll opening under warmer conditions, for which thidiazuron and ethephon were most effective. Under cooler conditions, dimethipin and ethephon were relatively ineffective for boll opening enhancement, although this combination effectively defoliated the crop. These interactions suggest that cotton producers should consider both the expected temperature regime and the crop response that they seek when mixing harvest aids.

ABSTRACT

Ethephon (2-chloroethyl phosphonic acid) may interact with various defoliants in cotton (*Gossypium hirsutum* L.), because of differences in mode of action or optimal temperatures for activity. Field temperatures for harvest aids are unpredictable, but later plantings are more likely to encounter cooler ambient temperatures than earlier plantings. We planted 'Deltapine 50' cotton in late April and mid-May for 3 years at the West Tennessee Experiment Station to study harvest-aid responses under different temperature regimes. Defoliants were tribufos (*S,S,S*,-tributyl phosphorotrithioate); dimethipin (2,3-dihydro-5,6-dimethyl-1,4-dithiin 1,1,4,4-tetraoxide); thidiazuron (*N*-phenyl-*N*'-1,2,3-thiadiazol-5-ylurea), and an untreated check, applied at 53 ± 5% open bolls with and without ethephon. Cumulative degree-days after treatment (base 15.6^{o} C) to final harvest ranged from 86 to 147 in the early plantings, and from 37 to 61 in later plantings. Interactions affecting defoliation, boll opening, and lint yields were more common under cooler conditions of the later plantings. Ethephon increased defoliation with thidiazuron more than with tribufos or dimethipin under cooler conditions. Tribufos or dimethipin defoliated faster than thidiazuron under cooler temperatures. Boll opening response to ethephon was reduced by tribufos in two warmer tests, and it was reduced by dimethipin in cooler conditions, relative to thidiazuron. Across defoliants, ethephon increased total lint yields in two tests under cooler conditions, but it decreased yields slightly in the warmest test. Optimum defoliation and boll opening responses require the use of different defoliants with ethephon as field temperatures change.

Various harvest-aid chemicals prepare the cotton crop for harvest by enhancing defoliation, desiccation, and boll opening, or by inhibiting regrowth. Chemicals that have one or more of these effects are frequently applied as mixtures to increase the likelihood of a favorable response (Snipes and Cathey, 1992), or to optimize activity and reduce costs (Supak, 1995). Relatively little has been published, however, on possible interactions between different types of harvest aids in field-grown cotton.

One reason that harvest-aid chemicals may interact is due to differences in mode of action. Defoliants such as tribufos, dimethipin, and thidiazuron cause leaves to abscise prematurely by increasing leaf ethylene concentrations. Tribufos injures the palisade cells in leaves (Morgan, 1983), while dimethipin causes leaf cells to slowly lose water, causing the leaf to generate ethylene (Hake et al., 1990). Both of these are considered contact-type defoliants, whereas thidiazuron has growth-regulator properties. Thidiazuron increases the concentration of ethylene relative to auxin in leaf petioles, which activates the leaf abscission layer (Suttle, 1985, 1988).

Ethephon is an ethylene precursor that is used primarily as a boll-opening compound in cotton, although it may also enhance defoliation (Snipes and Baskin, 1994). In spite of their ethylene-generating effects in the plant, defoliants rarely have been reported to enhance boll-opening activity of ethephon. Ethephon effects on boll dehiscence were not altered by the addition of tribufos (Cathey et al., 1982). However, a mixture of tribufos and ethephon produced more defoliation than either tribufos or ethephon alone, suggesting a complementary

Table 1. Cultural calendar and crop maturity at time of harvest-aid treatment of early and late-planted cotton, 1994 to 1996.

	Early planted			Late planted		
	1994	1995	1996	1994	1995	1996
Planting date	26 Apr.	28 Apr.	26 Apr.	19 May	16 May	17 May
Treatment date	16 Sept.	14 Sept.	5 Sept.	6 Oct.	25 Sept.	23 Sept.
Harvest dates:						
First harvest	30 Sept.	28 Sept.	19 Sept.	21 Oct.	9 Oct.	7 Oct.
Second harvest	17 Oct.	12 Oct.	3 Oct.	1 Nov.	23 Oct.	24 Oct.
Crop maturity:						
NACB†	5.3	4.4	4.2	3.7	3.7	2.6
Open bolls, %	49	51	50	49	57	54

† Nodes above cracked boll to the highest harvestable boll.

Table 2. Application rates of harvest-aid treatments.

Treatment no.	Defoliant	kg a.i. ha^{-1}	Boll opener	kg a.i. ha^{-1}
1	None	0	None	0
2	None	0	Ethephon	1.12
3	Tribufos	1.26	None	0
4	Tribufos	0.63	Ethephon	1.12
5	Thidiazuron	0.112	None	0
6	Thidiazuron	0.056	Ethephon	1.12
7	Dimethipin†	0.34	None	0
8	Dimethipin†	0.28	Ethephon	1.12

† Crop oil concentrate added to dimethipin treatments at 1.25% v/v.

interaction. Working with juvenile greenhouse-grown cotton, Durham and Morgan (1984) found that ethephon promoted leaf abscission in combination with dimethipin, but not with thidiazuron.

If ethephon increases the number of open bolls at harvest, it may increase total harvested yield; if it reduces boll weight by opening small bolls prematurely, it may decrease yield (Smith et al., 1986). Lint yield may be unchanged if one of these yield components compensates for the other. Cathey et al. (1982) found that the size of bolls that opened after treatment was 11% smaller with ethephon than without, but that total seedcotton yields were unaffected. Little information has been published on possible interactions of defoliants with ethephon on lint yields.

Another source of possible interactions arises from different temperature requirements for optimal activity of different harvest-aid chemicals. Cathey (1986) suggested that minimum temperatures above 16°C for 3 to 4 days after application are critical for defoliant activity. Hake et al. (1996) reported that tribufos and dimethipin have a lower minimum temperature requirement (12.8 to 15.6°C) than ethephon (15.6°C) or thidiazuron (18.3°C). This observation suggests that thidiazuron may interact less with ethephon under cool conditions than contact-type defoliants such as tribufos or dimethipin. In practice, field temperature regimes during and after application are often unpredictable. Along the northern edge of the U.S. Cotton Belt, however, cool ambient temperatures are more likely

Table 3. Air temperature at time of treatment, degree-day accumulation after treatment (DDAT), and average daily minimum temperature (T_{min}) after treatment of early and late-planted cotton, 1994 to 1996.

	Early planted			Late planted		
	1994	1995	1996	1994	1995	1996
	---------------------------------------ºC---------------------------------------					
Air temp. at treatment	26	29	26	23	19	24
DDAT to 7 DAT[†]	33	51	66	13	22	31
DDAT to 14 DAT	45	60	88	24	44	47
DDAT to 1st harvest	47	60	88	29	44	47
DDAT to 2nd harvest	86	107	147	37	66	61
Average daily T_{min}						
0 to 3 DAT	16	20	19	13	10	16
4 to 7 DAT	12	15	19	9	15	14
8 to 14 DAT	9	8	12	13	11	12

[†] DAT = days after treatment.

Table 4. Harvest-aid effects on defoliation of early-planted cotton under warm conditions, 7 and 14 days after treatment (DAT), and observed significance levels of main treatment effects and interactions.

		1994		1995		1996	
Defoliant	Boll opener	7 DAT	14 DAT	7 DAT	14 DAT	7 DAT	14 DAT
		-----------------% defoliation-----------------					
None	None	34	64	8	38	20	23
	Ethephon	55	83	18	50	43	46
Tribufos	None	66	84	49	81	65	79
	Ethephon	78	91	55	85	68	83
Thidiazuron	None	38	70	44	71	75	90
	Ethephon	59	85	43	78	80	88
Dimethipin	None	73	81	35	72	55	73
	Ethephon	84	93	50	79	68	83
$LSD_{0.05}$		14	10	16	13	16	12
		-----------------P values-----------------					
Defoliant		<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Boll opener		<0.01	<0.01	0.07	0.03	0.01	0.01
Interaction		>0.50	0.39	>0.50	>0.50	0.29	0.02

Table 5. Harvest-aid effects on defoliation of late-planted cotton under cool conditions, 7 and 14 days after treatment (DAT), and observed significance levels of main treatment effects and interactions.

Defoliant	Boll opener	1994 7 DAT	1994 14 DAT	1995 7 DAT	1995 14 DAT	1996 7 DAT	1996 14 DAT
		% defoliation					
None	None	40	64	25	38	10	11
	Ethephon	48	79	38	78	60	84
Tribufos	None	50	83	70	83	71	83
	Ethephon	85	90	81	86	86	94
Thidiazuron	None	33	63	20	29	40	53
	Ethephon	56	79	35	69	64	86
Dimethipin	None	43	85	50	63	74	89
	Ethephon	73	91	66	71	81	93
$LSD_{0.05}$		17	11	22	16	11	9
		P values					
Defoliant		<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Boll opener		<0.01	<0.01	0.02	<0.01	<0.01	<0.01
Interaction		0.11	>0.50	>0.50	<0.01	<0.01	<0.01

to prevail during defoliation of late-planted cotton than in earlier plantings.

The objectives of this research were to determine the interactive effects of defoliants and a boll opener on defoliation, boll opening, and yield of early and late-planted cotton, and to relate these effects to the temperature regimes prevalent during and after treatment.

MATERIALS AND METHODS

Deltapine 50 was planted at the West Tennessee Experiment Station in late April and mid-May of 1994, 1995, and 1996 (Table 1). The early (late April) and late (mid-May) plantings were adjacent to each other on a Loring-Calloway silt loam soil (fine-silty, mixed, thermic Typic Fragiudalf). Row spacing was 97 cm, and standard cultural practices recommended by the University of Tennessee for cotton production were followed (Shelby, 1996).

Each planting was divided into four-row plots, each 9.1-m long, to which harvest-aid treatments were applied with a high-clearance sprayer. All treatments were applied at 53 ± 5% open bolls, using a CO_2-pressurized boom. The boom applied 93 L of solution ha^{-1} through two hollow-cone nozzles per row, operating at 276 KPa. Crop maturity at the time of treatment is shown in Table 1. The number of nodes from the highest cracked boll to the highest harvestable boll was counted on 20 plants at random in each replication. A boll was considered harvestable if cotton from one or more locks could be removed by a spindle picker by final harvest.

Treatments were arranged in a factorial randomized complete block design with four replications. One factor consisted of the defoliants tribufos, dimethipin, and thidiazuron, along with an untreated check. The other factor consisted of the boll opener ethephon and an untreated check. Application rates of these harvest aids are shown in Table 2. Combinations of defoliants and the boll opener were applied together as mixtures, following label directions. A crop oil concentrate was added to dimethipin treatments at 1.25% v/v.

Defoliation was evaluated at 7 and 14 days after treatment by visually estimating the percentage of leaves present at the time of treatment that were removed by treatment. All visual estimates were made by the same investigator. Boll opening at 7 and 14 days after treatment was calculated as the

Table 6. Harvest-aid effects on boll opening of early-planted cotton under warm conditions, 7 and 14 days after treatment (DAT), and observed significance levels of main treatment effects and interactions.

		1994		1995		1996	
Defoliant	**Boll opener**	**7 DAT**	**14 DAT**	**7 DAT**	**14 DAT**	**7 DAT**	**14 DAT**
		---% open---					
None	None	60	71	64	76	70	85
	Ethephon	66	82	65	84	86	94
Tribufos	None	57	73	65	77	73	89
	Ethephon	61	80	59	76	72	85
Thidiazuron	None	54	68	64	73	62	87
	Ethephon	60	85	68	85	84	94
Dimethipin	None	47	63	60	72	64	77
	Ethephon	66	81	71	84	83	93
$LSD_{0.05}$		12	13	ns	11	12	10
		---P values---					
Defoliant		0.37	>0.50	>0.50	>0.50	>0.50	0.36
Boll opener		0.01	<0.01	>0.50	0.01	<0.01	0.01
Interaction		0.29	>0.50	0.30	0.32	0.04	0.06

percentage of total bolls that were harvestable at the time of observation, based on boll counts along a 1-m row segment of each plot. All data were collected from the two center rows of each plot, which were harvested with a John Deere 9930 spindle picker at 14 ± 1 d after treatment, and at 28 ± 3 d after treatment. Seedcotton from each plot was weighed, and a subsample was weighed, air-dried, and ginned on a 20-saw Continental gin equipped with dual inclined cleaners and two lint cleaners. Lint was weighed to calculate gin turnout and lint yield. Data were analyzed as a 4 by 2 factorial randomized complete block (Steel and Torrie, 1980).

Daily maximum and minimum air temperatures were measured in a standard U.S. Weather Service instrument shelter at the West Tennessee Experiment Station. Cumulative degree-days after treatment were calculated as described by Supak (1984), using a base temperature of 15.6°C.

RESULTS AND DISCUSSION

Air temperatures at the time of treatment ranged from 26 to 29°C in early planted cotton, and from 19 to 24°C in the later plantings (Table 3). More heat units accumulated between treatment and final harvest in earlier than in later plantings. Average daily minimum temperatures during the first 3 days after treatment ranged from 16 to 20°C in the earlier plantings, and from 10 to 16°C in the later plantings. Different planting dates therefore resulted in temperature regimes above and below the critical minimum temperature of 16°C proposed by Cathey (1986).

Tribufos or dimethipin produced more defoliation by 7 and 14 days after treatment than did natural senescence in the untreated cotton under both warm (Table 4) and cool conditions (Table 5). Defoliation was not significantly higher with thidiazuron than in the untreated cotton in the early planted 1994 cotton (Table 4), and the later planted 1994 and 1995 experiments (Table 5). These responses are consistent with temperature requirements for these defoliants reported by Hake et al. (1996).

Ethephon increased defoliation under warm- and cool-temperature regimes, but significant ethephon-defoliant interactions were also observed. Under very warm conditions in 1996, ethephon did not increase the defoliation response to tribufos or

Table 7. Harvest-aid effects on boll opening of late planted cotton under cool conditions, 7 and 14 d after treatment (DAT), and observed significance levels of main treatment effects and interactions.

		1994		1995		1996	
Defoliant	Boll opener	7 DAT	14 DAT	7 DAT	14 DAT	7 DAT	14 DAT
		% open					
None	None	56	60	73	84	82	94
	Ethephon	59	77	82	96	80	94
Tribufos	None	53	55	63	74	78	88
	Ethephon	54	69	71	86	79	92
Thidiazuron	None	53	77	68	85	73	84
	Ethephon	45	64	75	94	86	97
Dimethipin	None	58	65	73	87	70	82
	Ethephon	49	63	71	88	58	81
$LSD_{0.05}$		ns	16	14	9	18	12
		P values					
Defoliant		>0.50	>0.50	0.20	0.02	0.03	0.05
Boll opener		>0.50	0.03	0.09	<0.01	>0.50	0.25
Interaction		>0.50	0.35	>0.50	0.31	0.28	0.33

thidiazuron, although it significantly increased defoliation with dimethipin or by itself (Table 4). Interactions with ethephon were also observed under cooler conditions in 1995 and 1996 (Table 5). Defoliation responses to ethephon were relatively larger without a defoliant or with thidiazuron than in combination with tribufos or dimethipin. However, the latter defoliants were more effective than thidiazuron under cooler conditions. Most of these interactions can be attributed to a greater relative response to ethylene applied alone, as compared to its combined effect with a defoliant.

Defoliants did not directly influence boll opening under warm conditions (Table 6), but differences were observed when bolls opened under cooler conditions (Table 7). In 1996, boll opening was less with dimethipin than with other defoliants or the check under cool conditions. After dimethipin application, the capsule walls of closed bolls were visibly more desiccated than in other plots, which may have interfered with boll dehiscence. Under warmer conditions, ethephon increased the percent of open bolls by 7 days after treatment in 2 years, and by 14 days after treatment in all years (Table 6). Under warm conditions in 1995 and 1996, however, ethephon did not increase boll opening in combination with tribufos. This produced a significant interaction in 1996. Under cooler conditions, ethephon required more than 7 days to significantly increase boll opening (Table 7). Under these conditions, weak ($P = 0.31$ to 0.35) ethephon-defoliant interactions at 14 days after treatment each year can be attributed to lack of boll opening response to ethephon in combination with dimethipin. These interactions are consistent with ethephon labels (e.g., Rhône-Poulenc Ag Co., 1997) that advise of possible reduction in boll-opening response to ethephon when mixed with defoliants.

Lint yields at first harvest (data not shown) had responses similar to boll opening at 14 days after treatment. Ethephon increased first-harvest yields by 10 to 20% in all temperature regimes except one. The yield response to ethephon did not reach statistical significance ($P = 0.20$) under very warm conditions of the early planted 1996 crop, with 88 degree-days after treatment. Defoliants did not significantly influence lint yield at first harvest in early or late plantings. Weak ($P > 0.11$) ethephon-defoliant interactions were attributable to reductions

Table 8. Harvest-aid effects on total lint yields of early and late-planted cotton, 1994 to 1996, and observed significance levels of main treatment effects and interactions.

		Early planted			Late planted		
Defoliant	**Boll opener**	**1994**	**1995**	**1996**	**1994**	**1995**	**1996**
		$Mg\ ha^{-1}$					
None	**None**	**1.49**	**1.18**	**1.10**	**0.95**	**0.83**	**1.01**
	Ethephon	**1.61**	**1.15**	**1.09**	**1.07**	**0.99**	**1.06**
Tribufos	**None**	**1.55**	**1.13**	**1.14**	**0.99**	**0.82**	**1.01**
	Ethephon	**1.54**	**1.21**	**1.05**	**1.08**	**0.94**	**1.05**
Thidiazuron	**None**	**1.53**	**1.17**	**1.15**	**0.93**	**0.82**	**1.02**
	Ethephon	**1.63**	**1.23**	**1.10**	**0.97**	**0.91**	**1.11**
Dimethipin	**None**	**1.60**	**1.07**	**1.13**	**0.97**	**0.91**	**1.11**
	Ethephon	**1.67**	**1.24**	**1.08**	**1.04**	**0.91**	**1.07**
$LSD_{0.05}$		**ns**	**0.09**	**0.07**	**0.15**	**0.14**	**ns**
		P values					
Defoliant		**0.35**	**>0.50**	**>0.50**	**>0.50**	**>0.50**	**0.34**
Boll opener		**0.08**	**<0.01**	**0.05**	**0.03**	**0.01**	**>0.50**
Interaction		**>0.50**	**0.02**	**>0.50**	**0.21**	**0.38**	**>0.50**

in ethephon response by defoliants that were similar to reductions in boll-opening response.

Total lint yields were not affected by defoliants, but ethephon significantly increased total yields in two tests under cooler conditions with 37 and 66 degree-days after treatment (Table 8). However, ethephon decreased yield slightly in the early planted 1996 experiment in which bolls opened under very warm conditions. In this case, the temperature regime was probably adequate to open all bolls by second harvest (with 147 degree-days after treatment) without ethephon. However, total boll numbers were equivalent (not shown) and boll opening was enhanced by ethephon in this test (Table 6). Thus, the slight yield reduction due to ethephon may be attributable to smaller boll size as Smith et al. (1986) described, associated with faster boll-opening response to ethephon under very warm conditions. There was no yield increase from an ethephon-only treatment in the early planted 1995 test, which was reflected in a significant ethephon-defoliant interaction.

This series of experiments revealed several ethephon-defoliant interactions that may be influenced by temperature. Under cooler conditions, defoliation was enhanced more by ethephon when it was mixed with thidiazuron than with tribufos or dimethipin. However, either tribufos or dimethipin was a more effective defoliant than thidiazuron under these conditions. Another type of interaction involved reduction in boll-opening response to ethephon in combination with tribufos under warmer conditions or by dimethipin under cooler conditions. It is likely that relative responses to defoliants and ethephon were also conditioned by crop water status in these experiments, which merits additional research.

Ethephon-defoliant interactions warrant consideration when mixing harvest aids for different temperature regimes in the field. Cotton producers should consider both the expected temperature regime and the crop response that they seek (i.e., defoliation vs. boll opening). For instance, the most effective combination for cool-weather defoliation was tribufos and ethephon, but this combination was relatively ineffective in enhancing boll opening under warmer conditions, where thidiazuron and ethephon was a more effective combination. In general, mixtures of harvest-aid chemicals with growth regulating properties were effective only if sufficient heat units accumulated after treatment for physiological activity.

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