Etiology of Tomato Fruit Rots and Evaluation of Cultural and Chemical Treatments for Their Control

C. W. Jones and S. M. McCarter

Graduate Assistant and Associate Professor, Department of Plant Pathology and Plant Genetics, University of Georgia, Athens 30602.

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ABSTRACT

Rhizoctonia solani was the major cause of tomato fruit rots at four field sites in Georgia. *Sclerotium rolfsii* and *Phytophthora parasitica* were also important, but occurred sporadically. Six other fungi, including *Colletotrichum phomoides* and *C. gloeosporioides* were isolated infrequently. Soft-rot bacteria (*Erwinia* and other genera) caused significant losses of cracked and injured fruits. Paper mulch significantly reduced rot losses caused by *R. solani* and *S. rolfsii* and increased yields. However, captan or Isobac applied to the paper mulch did not further reduce rot losses. Isobac applied to the soil failed to decrease rot losses and captan, applied similarly, gave variable results. Sodium azide reduced rot losses in one test, indicating a need for further testing. *Colletotrichum gloeosporioides* was highly virulent on both injured and noninjured tomatoes in laboratory pathogenicity tests. *Fusarium roseum, F. solani, F. oxysporum, Mucor* sp., and *Geotrichum* sp. caused damage to injured fruit but were generally poor pathogens on healthy noninjured fruit.

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Fruit rots of tomato (*Lycopersicon esculentum* Mill.) are a serious production problem under the warm moist conditions of the southeastern United States. Tomato fruits may be attacked at any stage of maturity, but most of the damage occurs when fruits on or near the soil begin to ripen. Mechanical harvesting requirements increase the severity of the problem, because ripe fruits must remain in contact with the soil for longer periods before harvest (1, 2). The principal organisms reported to cause fruit rots include *Rhizoctonia solani* Kuehn, *Phytophthora parasitica* Dast., *Colletotrichum phomoides* (Sacc.) Chester, *Sclerotium rolfsii* Sacc., and soft-rot bacteria (2, 10). Control measures usually recommended for fruit rots are staking to prevent fruit contact with the soil, and avoiding poorly drained areas where rot losses are highest (16). Other control measures that have been evaluated, or are being tested, include the use of soil amendments or straw mulches (6, 15), film mulches (7, 9, 11, 14), fungicides (2, 3, 4, 5, 10, 16) and host resistance (1). In the present studies, we further determined organisms involved in the fruit-rot complex and evaluated several promising control measures. An abstract of a portion of this work has appeared (12).

MATERIALS AND METHODS.—Field plots were established in Georgia at Athens and Midville in 1971; at Athens, Midville, and Chatsworth in 1972; and at Athens and Tifton in 1973. All plots were fertilized and limed for tomato production according to soil test results. Irrigation was used as needed at all locations except Chatsworth. Diphenamid (N, N-dimethyl-2,2-diphenyl acetamide, Dymid, 5.6 kg/ha) or trifluralin (*a, a, a*-trifluoro-2,6-dinitro-N,N-dipropyl-*p*-toluidine, Treflan, 0.56 kg/ha) was applied for weed control.

Tomato cultivars used were Chico III in 1971; Marion and Campbell 28 in 1972; and Marion and Campbell 28 at Athens and Walter at Tifton in 1973. Plants for all tests except Tifton were grown in the greenhouse singly in 266-ml paper cups filled with methyl bromide-fumigated soil. Transplants were hand-planted in the field and given 828 ml of Peters water-soluble fertilizer solution (20-20-20, 2.4 g/liter). Transplants of the Walter cultivar, obtained from a commercial grower in Florida, were used at Tifton. Maneb (manganese ethylenebisdithiocarbamate, Manzate D, or Dithane M-22 Special 80%, 2.24 kg/ha) and carbaryl (1-napthyl methylcarbamate, Sevin 80%, 2.24 kg/ha) were applied at 7- to 10-day intervals to control foliar pathogens and insects. Methomyl (S-methyl-N[(methylcarbamoyl)oxy]thioacetamidate, Lannate 90%, 0.56 kg/ha) was used as needed for fruitworm control.

Six treatments were evaluated for fruit rot control during the 1971 tests at Athens and Midville, and treatments were added or deleted in later tests according to their performance. In 1971, plants received the following treatments: (i) paper mulch alone; (ii) paper mulch with captan; (iii) paper mulch with Isobac; (iv) captan sprayed on the soil; (v) Isobac sprayed on the soil; (vi) straw mulch alone; and (vii) control. Captan and Isobac were applied from fruit maturity through harvest. In the 1972 tests, the Isobac and straw mulch treatments were deleted and the captan application altered so that the chemical was applied either prior to (designated "preripening") or during (designated "ripening") fruit ripening. The 1973 test at Athens was similar, except that a sodium azide treatment was added. Only paper mulch was evaluated in the 1973 test at Tifton.

Captan (N-[(trichloromethyl)thio]4-cyclohexene-1,2-dicarboximide, Stauffer Captan 50%, 6.7 kg/ha in ca. 900 liters water) was applied to the soil or paper under and around plants with a 17-liter Hudson back-mounted hand-operated sprayer with a pressure gauge. Applications were made at 7- to 10-day intervals in 1971 and 1972 and at 14-day intervals in 1973. The preripening applications began at first fruit maturity and ended when the first fruits ripened. The ripening applications began at first fruit ripening and continued through harvest. Isobac (monosodium salt of hexachlorophene, Isobac 20, 290 ml/ha) was applied similarly at 7- to 10-day intervals from fruit maturity through harvest in 1971. In 1971, an oat straw mulch was applied under the plants as the fruit reached maturity. Sodium azide (17.9 kg/ha) was broadcast by hand and incorporated into the top 1.0 cm of soil as the first fruits reached maturity.

The paper mulch used in all tests was a tan or black

(Tifton test only) biodegradable paper (E-Z Mulch, Gulf States Paper Corporation, Oneco, Florida) coated on both sides with a thin layer of polyethylene. In 1971, the paper was applied by hand before plants became prostrate. Slits were made in the paper at the location of each stem to facilitate sliding the paper under the plants. The mulch was applied by hand in 1972 and with a modified Yellow-Devil sheet mulch layer (Mechanical Transplant Company, Holland, Michigan) in 1973, and plants were transplanted directly through holes made in the mulch with a knife or modified bulb planter. All beds were 0.76 m wide on 0.97-m centers in 1971 and 1972, and 1.02 m on 1.68-m centers in 1973. In all tests, beds were 15 m long. Plants were spaced 0.76 m apart in all tests except at Tifton where they were 0.3 m apart. Treatments were arranged in a randomized complete block design with four to six replications.

Multiple hand harvests were made at 7- to 10-day intervals from 12 representative plants in each treatment, beginning when the first fruits were completely ripe. Diseased and healthy fruits were separated and the yield of healthy fruit determined. Rotted fruits were grouped according to causal factor by visual inspection. Isolations were made when the cause of the rot could not be determined in the field. Sections (5-mm square) taken from the edge of each lesion were plated on 2% water agar and incubated at 30 C. Resulting fungal colonies were transferred to potato-dextrose agar (PDA, Difco) plates and incubated at 30 C. Pure cultures of the isolates were stored on PDA slants at 5 C for later identification, and for pathogenicity studies. The various soft-rotting bacteria associated with decaying fruits were not identified to species.

Laboratory studies were made to determine the pathogenicity of selected fungi isolated from decaying fruits. Cultures were grown at 30 C in petri plates on PDA. Mycelial plugs 5 mm in diam, cut from the periphery of the colonies with a sterile cork borer, were placed on surface-sterilized (3 min in 0.5% sodium hypochlorite containing 20 g/liter of detergent) tomato fruits with the mycelium side in contact with the cuticle. Ten healthy mature-green and 10 healthy ripe field-grown fruits were inoculated with each isolate. Two mycelial plugs were placed on the opposite sides of each fruit. One plug was placed on the noninjured cuticle; the second was placed over a wound (2-mm deep) made with a sterilized dissecting needle to simulate wounding that might occur on fruits in the field. Each plug was held in place with a 22-mm diam circular adhesive bandage. The inoculated fruits were incubated at 30 C on a wire rack placed inside a covered humidity chamber (9 × 25 cm). Lesion development was recorded at 2-day intervals for 11 days.

RESULTS.—*Etiology of fruit rots.*—*Rhizoctonia solani* was the most common organism at all locations except Athens in 1971 (Table 1). *Phytophthora parasitica,* which was the most important rot organism at Athens during 1971, occurred less frequently at that location in 1972 and 1973, but was not observed or isolated from fruits at the three other locations. *S. rolfsii* was the second most important cause of fungal fruit rots, when all tests were considered. It was observed mainly at Midville during 1971 and 1972, and occurred rather infrequently or not at all in other tests. *Alternaria solani, A. tenuis* Auct., *Colletotrichum phomoides, C. gloeosporioides,* (Penz.) Sacc., *Fusarium roseum* (Lk.) Snyd. & Hans., *F. solani* Snyd. & Hans., *F. oxysporum* Schlecht., *Mucor* sp., and *Geotrichum* sp. were other organisms isolated infrequently. Damage caused by soft rot bacteria (*Erwinia* and other genera) varied greatly with location depending mostly on environmental conditions that caused cracking of ripe fruits. Significant losses from blossom-end rot also occurred.

Control of fruit rots.—Paper mulch with or without a fungicide significantly reduced the incidence of Rhizoctonia rot in all tests regardless of the cultivar used (Table 2). Better control was obtained in 1972 and 1973 when plants were transplanted directly through the paper, than in 1971 when the mulch was applied under established plants. The addition of captan or Isobac to the paper mulch did not significantly decrease the incidence of fruit rot compared with the paper treatment alone. Captan on the soil significantly reduced the incidence of

TABLE 1. Causes of tomato fruit rots in control plots at three locations in Georgia during 1971-1973

Organism	Incidence of rot-producing organisms (%)[a]						
	1971		1972			1973	
	Athens	Midville	Athens	Midville	Chatsworth	Athens	Tifton
Rhizoctonia solani	40.8	66.2	41.1	74.9	48.7	57.2	76.0
Sclerotium rolfsii	2.0	11.8	8.7	8.5	0.4	0.0	4.2
Phytophthora parasitica	43.6	0.0	8.3	0.0	0.0	1.4	0.0
Alternaria spp. (*A. solani* and *A. tenuis*)	0.0	0.0	0.0	0.0	0.0	9.2	1.1
Colletotrichum spp. (*C. phomoides* and *C. gloeosporioides*)	0.0	0.0	0.0	0.0	0.0	1.7	2.1
Soft rot bacteria (*Erwinia* and other Genera)	4.8	8.1	26.3	9.3	43.4	28.2	11.1
Miscellaneous and unknown organisms[b]	8.8	13.9	15.6	7.3	7.5	2.3	5.5

[a]Each value is the percent of total rot caused by that organism. Each column totals 100 percent. Losses from blossom-end rot, sunscald, and insects were excluded.

[b]Includes *Fusarium roseum, F. solani, F. oxysporum, Mucor* sp. and *Geotrichum* sp. Fruits with multiple infections were included in this group.

TABLE 2. Influence of various treatments on the incidence of soil rot of tomato caused by *Rhizoctonia solani* at four locations in Georgia during 1971-1973[a]

	Number of rotted fruits per 12 plants[b]						
	1971		1972			1973	
Treatment	Athens	Midville	Athens	Midville	Chatsworth	Athens	Tifton
Paper mulch	31.0*	36.0*	2.7*	3.8*	5.8*	1.2*	2.5*
Paper mulch + captan	18.3*	35.5*	3.2*	3.5*	1.7*	1.0*	[c]
Paper mulch + Isobac	23.5*	40.7*					
Captan on soil[d]	38.7*	79.2*	25.5	74.2	23.8	27.0*	
Sodium azide on soil						30.2*	
Isobac on soil	54.3	132.5					
Straw mulch on soil	67.5	74.8*					
Control	69.3	147.4	21.5	84.7	25.0	45.8	27.1

[a]The tomato cultivars were Chico III in 1971, Marion in 1972, and Marion (Athens) and Walter (Tifton) in 1973.
[b]Entries followed by an asterisk (*) differ significantly from the control ($P = 0.05$).
[c]Blank spaces indicate the treatments were not included during that year.
[d]In 1972 captan was applied either from fruit maturity to the first fruit ripening (preripening sprays) or from fruit ripening through harvest (ripening sprays). Similar results were obtained so only the "ripening" treatment results are given.

rot at Athens and Midville in 1971, at Athens in 1973, but failed to provide significant control at the three test locations in 1972. Sodium azide significantly lowered the incidence of Rhizoctonia rot on the Marion cultivar at Athens during the 1973 test. The straw mulch gave erratic control. None of the treatments significantly affected the incidence of buckeye rot (*P. parasitica*) at Athens in 1971, or the bacterial soft rots that occurred frequently at all locations. *Alternaria* spp. and *Colletotrichum* spp. did not occur frequently enough to evaluate the various treatments. The incidence of blossom-end rot was highest on paper mulch, especially in the C-28 cultivar.

Yield.—The most representative yield data were obtained in 1972 (Table 3). Yields of both Marion and Campbell 28 cultivars were significantly increased at all three locations when paper mulch was used alone or with captan. Neither the chemical treatments applied to the soil nor the straw mulch increased yields in any of the tests.

Pathogenicity tests.—The pathogenicity of *R. solani*, *S. rolfsii*, *P. parasitica*, and *A. solani* on tomato fruits is well established; therefore, these organisms were not studied. However, little has been reported on the pathogenicity of some of the organisms isolated from decaying fruits in these tests.

C. gloeosporioides was the only organism of six tested that was highly virulent on wounded and nonwounded green and ripe fruits (Fig. 1). The *Fusarium* spp. varied in their capacity to attack fruits. Generally, disease development was most rapid on wounded ripe fruits. Some lesions occurred on nonwounded ripe and wounded green fruits but nonwounded green fruits were usually not infected. *Mucor* sp. caused a rapid soft rot on wounded ripe fruits, but developed slowly on or did not infect in other inoculations. *Geotrichum* sp. caused a few slowly developing lesions on ripe and green wounded fruits, but did not infect nonwounded fruits.

TABLE 3. Fruit yield of two tomato cultivars receiving various treatments at three locations in Georgia during 1972

	Fruit yield per 12 plants[a] (kg)		
Cultivar and treatment	Athens	Chatsworth	Midville
Marion			
Paper mulch	40.2*[b]	51.3*	45.4*
Paper mulch + captan	35.8*	48.4*	47.4*
Captan (on soil)	22.0	28.5	32.8
Control	20.7	28.3	36.8
Campbell 28			
Paper mulch	39.5*	51.4*	50.3*
Paper mulch + captan	36.4*	55.0*	47.2*
Captan (on soil)	26.1	22.5	43.3
Control	23.3	24.8	36.0

[a]Mean weight of healthy ripe fruit per 12 plants for each of six replications.
[b]Entries followed by an asterisk (*) differ significantly from the control ($P = 0.05$).

DISCUSSION.—The wide variation in the incidence of tomato fruit rot at the different locations, coupled with the somewhat consistent composition of the populations of fruit-rotting organisms, suggests that the environment affects the severity of fruit rot incidence, but does not greatly affect the nature of the parasitic population. An exception was *P. parasitica*, which occurred only at Athens where plots were poorly drained. *R. solani* was the most important cause of fruit rot at all locations. Similarly, Batson (2) found that *R. solani* accounted for 69% of the isolates from decaying fruits in Mississippi, with *S. rolfsii* and *Erwinia* spp. accounting for an additional 16%. Like Batson (2), we found *Colletotrichum* spp. to be relatively unimportant causes of fruit rot although they are important in other areas of the United States. Batson (2) suggested that fungicides such as maneb applied primarily for foliage diseases may also provide some control of these anthracnose fungi. Soft rots, caused by bacteria and associated mostly with fully ripened fruits, could have been avoided by harvesting the fruit at an earlier stage of ripening. We intentionally allowed fruits to reach the fully ripe stage to maximize fungal rots for treatment evaluation. Blossom-end rot was generally much more severe on Chico III and Campbell 28 cultivars, than on the Marion plants. The rapid and heavy fruit set by these cultivars, with the resulting increased requirements for moisture and

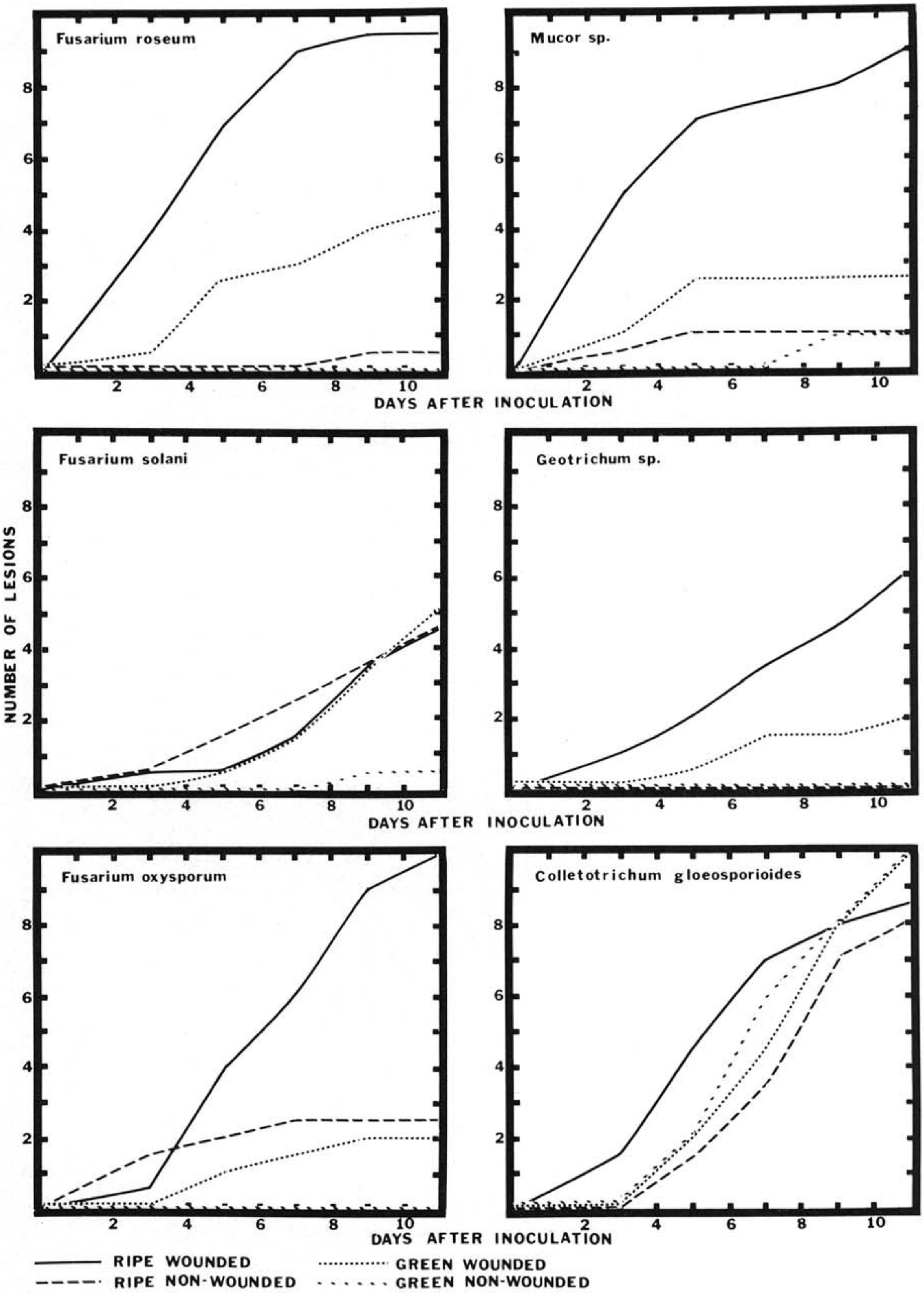

Fig. 1. Pathogenicity of six fungi on wounded and nonwounded green and ripe tomato fruits in laboratory tests. Each line represents the average number of lesions that developed when ten healthy tomato fruits were inoculated in each of two studies.

nutrients, may explain the higher incidence of blossom-end rot. Fruiting stress along with the balance of certain plant nutrients and available moisture in the soil interact to cause blossom-end rot (8). *C. gloeosporioides*, the only organism highly virulent in the pathogenicity tests, is potentially important as a fruit-rot organism. *Fusarium* spp., *Mucor* sp., and *Geotrichum* sp. are considered minor pathogens as they occur infrequently and attack noninjured fruit with difficulty.

Since *R. solani* is the principal fruit-rot organism, control of fruit rots must include measures effective against this pathogen. Paper or other film mulches offer promise for the control of *R. solani* and *S. rolfsii*. Fruit-rot control with properly applied film mulch is so effective that the addition of a fungicide to the paper is not necessary. Film mulches offer several other advantages such as conserving moisture, providing weed control, preventing leaching of nutrients, preventing soil compaction, and sometimes favorably altering the temp for plant growth. Furthermore, paper mulches are biodegradable and do not have to be removed from the field at the end of the growing season. The significant increases in yield that occurred with the paper mulch treatments cannot be explained entirely on the basis of fruit rot control. In fact, in 1972, the greatest increases in yields with paper mulch occurred on the heavier soils at Athens and Chatsworth although fruit rot losses were higher at Midville. McCubbin and Westover (13) reported a similar response on heavier versus light soils with paper mulch.

Although paper and other film mulches appear to have potential, several problems must be resolved before they can be used most effectively. The higher incidence of blossom-end rot on paper mulch, especially with the Chico III and Campbell 28 cultivars, emphasizes the need for research on nutrition, particularly nutrient balance, and moisture control. Results of our Tifton test indicate that a severe moisture stress may develop in tomatoes grown with paper mulch on sandy soils with low moisture-holding capacity, regardless of the amount of water applied by sprinkler irrigation. Additional research is needed to develop methods for the control of the several variables that may result in failure with paper or other film mulches.

Control of the major tomato fruit rots with certain fungicides does not appear to be particularly promising, based on the results of the present tests. Further tests with additional fungicides are needed before a definitive conclusion can be reached. Favorable results with fungicides (2, 3, 4, 5, 10, 16) suggest the need for their further evaluation for fruit rot control under our conditions. Sodium azide should also be evaluated further since it reduced fruit rot losses in our tests.

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