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Papaya Postharvest Handling in Mexico: Use of Chitosan and Isothiocyanates to Control Postharvest Diseases

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ABSTRACT

The papaya fruit has worldwide and economic importance. Papayas are mostly eaten fresh, alone or as a component of fruit salads, juices, canned papaya cubes, leathers etc. The fruit is high in vitamins and minerals. Compared with other tropical fruits, papaya has high levels of vitamin C. Mexico is becoming the world's top papaya fruit-exporting country. Postharvest losses due to diseases are significantly high in papaya. Among others, *Colletotrichum gloeosporioides*, *Alternaria alternata* and *Fusarium oxysporum*, are fungal organisms acquired in the field during blossom and fruit development, others such as *Rhizopus stolonifer* and *Penicillium digitatum* are acquired during harvest and through handling. For growers and retailers, the common way to reduce the incidence of papaya diseases at the postharvest stage is applying synthetic fungicides. However, these compounds are systematically less effective in controlling fungi. In addition, there is a current trend to use less harmful products to humans and the environment. Chitosan, a derivative of chitin is a natural, biodegradable, nontoxic polymer with a wide range of uses in cosmetology, the food industry, biotechnology, medicine, and agriculture. The isothiocyanates, breakdown products derived from glucosinolates, belong to a class of sulphur-containing glucosides from different plant families such as Brassicacea, Caricaceae, and Cruciferaceae. Both chitosan and isothiocyanates are important natural compounds associated with their fungistatic or fungicidal properties against phytopathogens. This review summarizes the importance of the postharvest handling of papaya in Mexico for export and domestic markets, its contribution to the diet, and the potential of using chitosan and isothiocyanates as alternatives to synthetic fungicides in controlling the postharvest decay during the papaya supply chain.

Keywords: *Carica papaya*, natural compounds, postharvest handling, papaya storage rots
Abbreviations: ITC, isothiocyanate

CONTENTS

INTRODUCTION

The papaya, *Carica papaya* L., is a member of the family Caricaceae. It is believed to be native to southern Mexico, Guatemala, and Costa Rica (Teixeira da Silva *et al.* 2007). Cultivation has spread to the south mostly by Indians, and with the Spanish exploration, reached the Caribbean. The Spaniards also carried the fruit to the Philippines and from there, papaya seeds were taken to the Pacific Islands and India. By the mid-17th century, papaya has been distributed worldwide. To date, this fruit is grown in almost all tropical and subtropical regions of the world and the fruit is the most valued organ of the plant. Intensive papaya improvement programs all over the world have produced a great variety of cultivars. Worldwide production of papaya is approximately of 6,504,369 MT, and is produced in 54 different countries, with Brazil accounting for the 25% of total production, followed by Nigeria, India, and México in the fourth place (**Fig. 1A**). Mexico is the largest supplier of 'Maradol' papaya to the United States followed by Malaysia, Brazil and Belize with other cultivars (**Fig. 1B**) (USDA 2005).

'Maradol' that was obtained in Cuba is the most cultivated papaya in Mexico. This cultivar has good resistance

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Invited Review

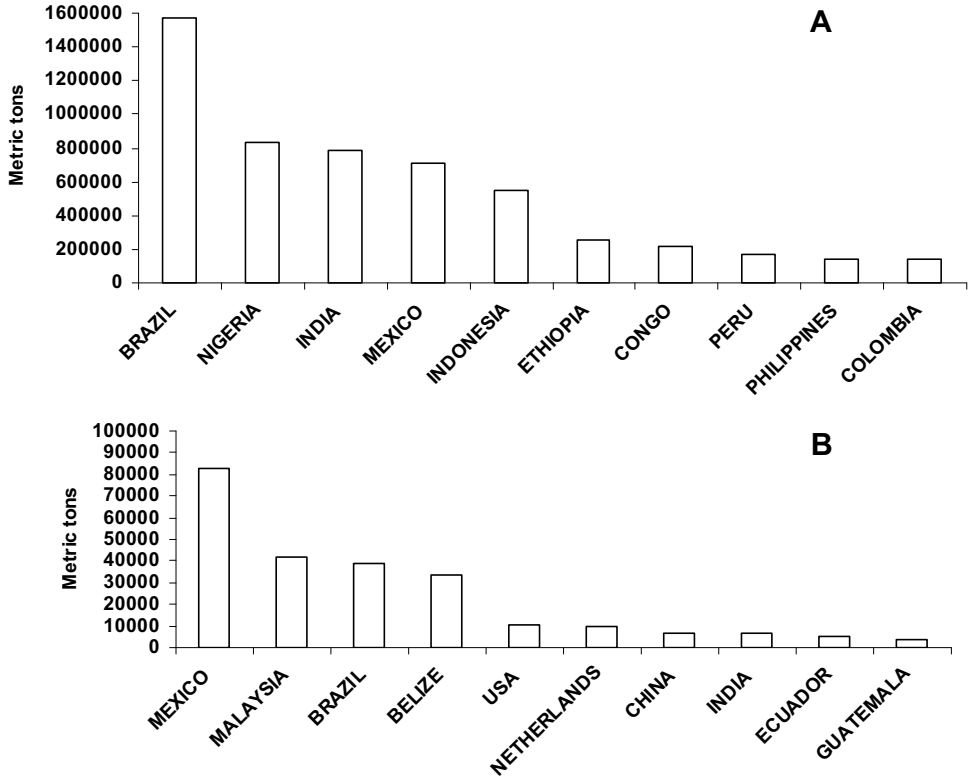

Fig. 1 World producers (**A**) and major exporters (**B**) of papaya fruits. Based on data from USDA (2005).

Fig. 2 Fruits of papaya 'Maradol'.

during transportation, and longer storage life than other native varieties such as 'Cera' and 'Coco' that currently are difficult to find in the markets of Mexico. Fruits of Maradol develop from hermaphrodite flowers that are large and oval, and the average fruit weight is approximately 1.5-2.5 kg. When the fruit is fully ripe, the skin is yellow and the flesh is orange to bright red salmon and sweet with approximately 12 °Brix (**Fig. 2**) (INIFAP 1997). Papayas from the 'Solo' group are cultivated in Mexico at low scale and mostly for export.

Uses and contribution to the diet

Overall, papaya is used largely for the fresh market (93%), with small amounts processed into juices and other food items. As a food source, papaya provides a good and affordable source of vitamins and minerals (**Table 1**). The fruit contains the same levels of vitamin C as that found in litchi, and mango fruits whereas its level of vitamin A is in higher quantities than in fruits such as orange, pineapple, and guava (Leung and Flores 1975).

Table 1 Nutrient content (in 100 g fresh weight) of the edible parts of commercial papaya fruits from different cultivars (Leung and Flores 1975; Rehm and Espig 1991; Yon 1994).

Water	84 -90 g
Energy	7.64-14.11 KJ Kg^{-1}
Crude protein	0.5-1.5 g
Crude fat	0.1-0.5 g
Digestible carbohydrates	7-13.5 g
Crude fibre	0.5-0.7 g
Thiamin, (Vit. B1)	0.03- 0.08 mg
Riboflavin, (Vit. B2)	0.03- 0.15 mg
Niacin	0.1-0.3 mg
Beta-carotene	1160-2500 µg
Vitamin C	46-71.0 mg
Calcium	11-31 mg
Phosphorus	7-17 mg
Iron	0.4-0.7 mg

PAPAYA POSTHARVEST HANDLING

Postharvest handling of papayas for export and national markets

In Mexico, most papayas are harvested when the first hint of yellow coloration appears in the skin. However, there is an enormous difference in postharvest handling for fruit meant for export and those to be sold in the national market. For export papayas, fruits must be treated with heat to minimize insect infestations and these must be handled inside an insect-proof packing house. Papayas are submitted to vapor treatment in a room with accurate temperature control and air circulation. After the center of the fruit reaches 47.2°C at a RH of 60 to 95% for 2 h, then they are immediately cooled in water at 20-25°C. Uniformly sized papayas are hand-packed into shipping cartons of 17 kg with 9, 10 or 11 pieces. Fruits are marketed as the color breaks, ¼, ½, and ¾

Fig. 3 Postharvest handling of papaya 'Maradol' at the national level.

ripe with foam mesh sleeves or foam padding at the bottom of the cartons. Papayas for the national market are submerged for 15-20 min in fungicide solution for anthracnose decay control. After treatment, fruits are air-dried and individually double-wrapped with paper, and then packed in cartons or plastic boxes or transported in bulk to distribution centers where, if necessary, they are ethylene-ripened. The usual concentration applied ranges between 100 to 150 ppm for 12 to 24 h (**Fig. 3**).

Constraints during postharvest papaya handling

Postharvest losses of papaya are normally due to mechanical damage, overripe fruit, and diseases caused by fungi (Capellini *et al*. 1988). In Mexico, the development of rots is a major problem during storage and marketing. In papaya, the maturity stage is closely related with fungal growth, as fruit maturity increases disease susceptibility as well. Anthracnose, caused by the fungus *Colletotrichum gloeosporioides*, is the major postharvest disease in papaya producing areas. During the last 5 years, *C. gloeosporioides* had affected 80% of the total production. Other important fungi such as *Fusarium oxysporum*, *Alternaria alternata*, *Penicillium digitatum*, and *Rhizopus stolonifer* cause serious losses during storage at the wholesale and retail markets (**Fig. 4**).

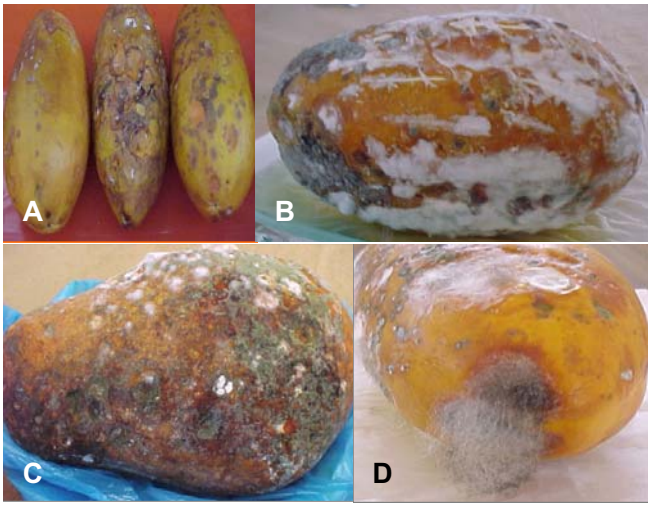

Fig. 4 Major postharvest fungi of papaya in 'Maradol' in production areas of Mexico. (**A**) *Colletotrichum gloeosporioides*, (**B**) *Fusarium oxysporum*, (**C**) *Penicillium digitatum*, and (**D**) *Rhizopus stolonifer*.

Controlling postharvest fungi of papaya fruits

In Mexico, papayas are commonly treated with fungicide to reduce postharvest rot. The most common fungicides used are Tecto® (Thiabendazol), applied at 2 g L^{-1} Mirage® and Sportak® (Phrochloraz) both used at 0.5 ml L^{-1} among others (INIFAP 1997). For export conditions, fungicides are also added after the heat treatment, consisted of dipping the fruit between 43 to 50°C during different intervals of time (20, 30 and 40 min) depending on the variety and pathogen to be controlled. However, during the last few years, growers and retailers have not achieved the same degree of control as they had done before. We believe that climatic changes of longest and heaviest rainy season, together with an increase in pathogen resistance, have led to a decreased efficacy of the chemicals. Additionally, export growers have been forced to examine other aspects such as contamination at various levels of the food chain due to the excessive use of these synthetic compounds. Therefore, other alternatives to extend shelf life by reducing disease incidence have been evaluated. Our research group has carried out studies on two natural products – chitosan and isothiocyanates.

CHITOSAN AS AN ALTERNATIVE FOR CONTROLLING POSTHARVEST FUNGI OF PAPAYA IN *IN VITRO* AND *IN SITU* STUDIES

Uses of chitosan in agriculture

Chitosan obtained by deacetylation of chitin is a natural, biodegradable, nontoxic polymer with various applications in agriculture (Sandford 1989; Larez 2008). Several lines of experimental investigation have demonstrated the chitosan efficacy to protect seedlings against pest and diseases, improve seed germination by inducing of resistance, promote plant growth, and consequently increase crop yield (Bhaskara Reddy *et al*. 1999; Ohta *et al*. 1999; Ren *et al*. 2001). An important attribute of this natural compound is associated with its fungistatic or fungicidal properties against pathogens of various fruits and vegetables. Growth of important postharvest fungi such as *A. alternata*, *F. oxysporum* and *R. stolonifer*, among many others, was inhibited with chitosan applications (Benhamou and Thériault 1992; Bautista-Baños *et al*. 2003, 2004a).

Effect of chitosan on survival of papaya fungi in *in vitro* studies

Investigations carried out in our laboratories have demonstrated the efficacy of chitosan in controlling the growth of various postharvest fungi of papaya in *in vitro* studies (Bautista-Baños *et al*. 2003, 2004b, 2005). Chitosan affected various stages of fungi development, and as reported with other phytopathogens, the inhibition increased as chitosan concentration increased. In our studies, *F. oxysporum* was found to be extremely sensitive to chitosan, since its growth was affected at all concentrations, including 0.5%. Meanwhile, chitosan at 1.5% onward affected the growth of *P. digitatum* and *R. stolonifer* compared with the control treatment (only PDA) (**Fig. 5A**). The growth of *Fusarium* at 0.5% began after the second day of treatment until the 10th day of incubation with a growth rate of 0.23 ($r^2 = 0.94$), compared with the control's normal growth rate (0.50, $r^2 = 0.92$). Mycelial growth of *P. digitatum* began after the second day on chitosan at 1.5% (**Fig. 5B**). *Rhizopus* growth began after the first day of incubation with chitosan at 1.5% (0.61, $r^2 = 0.89$) (**Fig. 5C**).

Sporulation was also affected by chitosan application. The sporulation of *Fusarium* was significantly reduced ($P \leq 0.001$) when treated with 0.5% chitosan. The opposite effect was observed with *P. digitatum* since higher sporulation (compared with control) occurred at both chitosan concentrations of 0.5 and 1.5% ($P \leq 0.001$) was shown. Chitosan at 1.5% significantly reduced the sporulation of *R. stolonifer* ($P \leq 0.001$) (**Table 2**). In further studies carried out in two isolates of *C. gloeosporioides*, we did not observe a defined pattern according to the type of chitosan tested (**Table 3**). In that study, in terms of mycelial growth and sporulation, results were variable and did not show a direct relationship with molecular weight. Chitosan slightly reduced the mycelial growth of both isolates of *C. gloeosporioides* contrary to results obtained from another report (Bautista-Baños *et al*. 2003). In that investigation, chitosan concentration up to 2.5% completely inhibited mycelial growth of *C. gloeosporioides*. Similar findings were reported by Hewajulige *et al*. (2007), however, in that study, in controlling mycelial growth of *C. gloeosporioides*, complete inhibition was reported at 1% concentration. It is evident that the chitosan response is also associated with the isolate types tested. After further research, we observed that sporulation was markedly inhibited in one isolate of *C. gloeosporioides* only, when it was grown on chitosan medium molecular weight of 1.5% (6.6×10^3) (Bautista-Baños *et al*. 2004b).

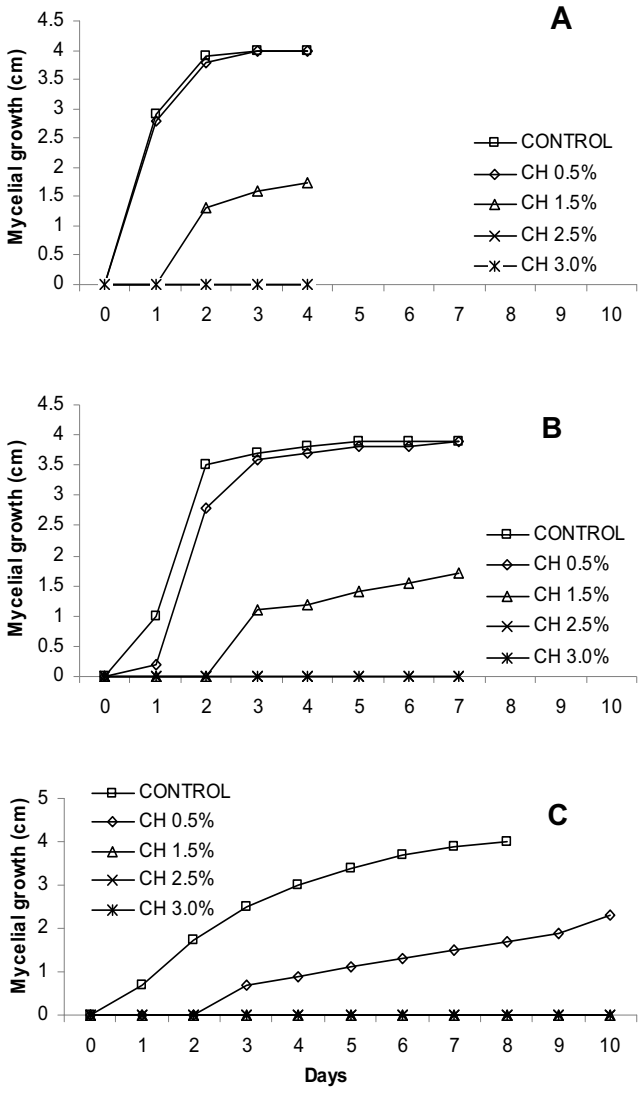

Fig. 5 Effect of chitosan at various concentrations on mycelial growth of (**A**) *Fusarium oxysporum*, (**B**) *Penicillium digitatum*, and (**C**) *Rhizopus stolonifer*.

Table 2 Effect of chitosan on sporulation of *Fusarium oxysporum*, *Penicillium digitatum* and *Rhizopus stolonifer* isolated from papaya fruit.

Treatment	Sporulation spores mL^{-1}		
	F. oxysporum	*P. digitatum*	*R. stolonifer*
Chitosan (%)			
0.5	3.5×10^5	4.2×10^7	1.5×10^6
1.5	-	2.1×10^7	1.3×10^6
2.5	-	-	-
3.0	-	-	-
Control	4.0×10^5	1.8×10^7c	1.8×10^6

Means separation within columns by Tukey's multiple test ($P \leq 0.05$).
- Since mycelial growth did not take place, no spores were counted.

Table 3 Effect of low, medium or high molecular weight-chitosan at various concentrations on mycelial growth and sporulation of two isolates of *Colletotrichum gloeosporioides* incubated at 25 ± 2°C.

Chitosan	Isolate 1 [x]		Isolate 2 [x]	
	Mycelial growth[y] (mm)	Sporulation[z] spores ml^{-1}	Mycelial growth[y] (mm)	Sporulation[z] spores ml^{-1}
Low molecular weight (concentration, %)				
0.5%	81.5 b	1.4×10^5 a	83.3 abc	1.4×10^5 abc
1.0%	80.8 cd	3.5×10^4 cde	84.1 ab	1.4×10^5 abc
1.5%	81.5 bc	5.0×10^4 bc	83.7 abc	1.0×10^5 bc
2.0%	78.1 cd	4.8×10^4 bc	83.0 abc	1.7×10^5 bc
Medium molecular weight (concentration, %)				
0.5%	81.2 bc	1.0×10^4 de	81.6 bc	1.6×10^5 abc
1.0%	81.4 bc	1.5×10^4 e	81.3 c	1.3×10^5 abc
1.5%	81.6 b	6.6×10^3 f	84.2 a	1.9×10^5 ab
2.0%	79.3 cd	2.8×10^4 cde	84.8 a	1.7×10^5 abc
High molecular weight (concentration, %)				
0.5%	81.8 b	8.1×10^4 b	83.6 abc	1.5×10^5 abc
1.0%	77.8 d	4.6×10^4 bcd	85.0 a	1.1×10^5 bc
1.5%	81.6 b	2.2×10^4 cde	84.6 a	1.4×10^5 abc
2.0%	79.2 cd	1.5×10^4 cde	84.8 a	1.5×10^4 cd
Control	85.0 a	4.2×10^4 cd	85.0 a	2.1×10^5 a

[x] Means separation within columns by Tukey's multiple range test at $P \leq 0.05$.
[y] 7 day incubation period.
[z] 11 day incubation period.

Effect of chitosan on the control of fungi in papaya fruits

To date there are few publications on the fungicidal effect of chitosan during the development of papaya in the field. In our investigation, the efficacy of chitosan applied in the field prior to harvest did not show any positive effect in controlling postharvest rot (**Table 4**) (Rojas-Estudillo 2005). In that study, we applied chitosan at three different concentrations (0.05, 0.15 and 0.25%) from the flowering stage to harvest. Overall, infection levels at the end of the storage period at 14°C were high among all treatments, including the one with synthetic fungicides. The lowest infection of 78.3% was observed with 0.15% chitosan concentration.

Table 4 Effect of preharvest application of chitosan on percentage infection, diseases severity, and storage time of naturally infected papayas.

Chitosan treatment	Percentage infection	Severity index	Storage days at 14°C
0.05%	100 a	2.0 a	14.7 a
0.15%	78.3 b	2.0 a	13.1 a
0.25%	100 a	2.0 a	14.8 a
Water	91.2 ab	2.0 a	12.7 b
Fungicide Benlate®	93.7 ab	2.0 a	11.8 b

Means separation within columns by Tukey's multiple range test at $P \leq 0.05$. Disease severity index: 2 = 1-25% of rotten fruit surface.

Table 5 Effect of postharvest application of chitosan on percentage infection and diseases severity of naturally infected papayas.

Chitosan treatment	Percentage infection P≤ 0.001	Severity index
Low molecular weight chitosan		
0.15%	30	2.0a
0.25%	30	2.0a
Medium molecular weight chitosan		
0.15%	10	2.0
0.25%	10	2.0
High molecular weight chitosan		
0.15%	30	2.0
0.25%	20	2.0
Water	70	2.0
Fungicide Benlate®	40	2.0

Disease severity index: 2 = 1-25% of rotten fruit surface.

Nevertheless, an important consequence of the preharvest application of chitosan was observed in the papaya by extending for 3 days the shelf life.

For postharvest evaluation of the effect of chitosan on controlling rot during storage, various authors have reported the fungicidal potential of chitosan to reduce anthracnose disease and other rots. According to Luna *et al*. (2001) infection levels of chitosan-treated papayas were halved at 3% concentration, while Sivakumar *et al*. (2005) found that chitosan at 1% alone or combined with other compounds such as ammonium carbonate and sodium carbonate reduced anthracnose disease in more than 85% of the cases. All authors agreed that fruit quality of the chitosan-treated papayas was not affected. In additional studies about different molecular weight of chitosan and its effect on disease incidence, we found that, regardless of molecular weight an excellent postharvest control of rots was achieved at concentrations of 0.15 and 0.35% (**Table 5**). In that investigation, severity index was similar among treatments.

ISOTHIOCYANATES AS AN ALTERNATIVE FOR CONTROLLING POSTHARVEST FUNGI OF PAPAYA IN *IN VITRO* AND *IN SITU* STUDIES

Use of isothiocyanates in agriculture

It is reported that the isothiocyanates (ITCs) (degradation products of glucosinolates) have several advantages over methyl bromide and other synthetic pesticides such as Captan® both commonly used in agriculture. They do not pose any danger to human health, and are harmless to the environment. Therefore, their use is in accordance with principles of sustainable agriculture. These compounds are usually found in several plants of the families Capparaceae, Brassicaceae, Koeberliniaceae, Moringaceae, Resedaceae and Tovariaceae (Rosa and Rodrigues 1999). A significant number of experiments have shown that cabbage, broccoli, mustard, horse radish, rapeseed (canola) tissues, or their seed extracts are toxic to several fungi. Incorporation of *Brassica nigra* and *B. juncea* containing 2-propenyl or allyl ITC were suppressive to *Fusarium sambucinum* (Mayton *et al*. 1996). Additional evidence of the involvement of a specific ITC in fungicidal activity has been reported by several authors. Hooker *et al*. in 1943 showed that allyl ITC and 3-butenyl ITC were very toxic toward *Colletotrichum circinans*, *Aspergillus alliaceus*, *A. niger*, and *Gibberella saubinetti*. Other authors have reported that phenylethyl ITC was very toxic toward *Botrytis cinerea* (Dawson *et al*. 1993) and G*aeumanomyces graminis* (Angus *et al*. 1994), benzyl ITC was very toxic to *Monilinia laxa* and *Mucor piriformis* (Mari *et al*. 1993) and allyl ITC was extremely effective in controlling *Sclerotium cepivorum* (Smolinska and Horbowicz 1999). The mechanism by which isothiocyanates (ITCs) inhibit microorganisms is not yet completely known. Nevertheless, experimental evidence supports the action of ITCs in living organisms; they carry out unspecific reactions with proteins of the microorganism (Kawakishi and Kaneko 1987; Delaquis and Mazza 1995; Cejpek *et al*. 2000). These reactions are thought to be taking place between the ITC (R-N=C=S) and the amino groups of the lysine R group, the sulfhydryl of the cysteine R groups and with disulfide bonds. After the reaction, the isothiocyanate remains covalently bound to the protein which brings changes in the tertiary structure of the protein and leads to partial or total loss of enzymatic activity (Tuls *et al*. 1989; Rawel *et al*. 1998; Yang *et al*. 2000). Although there are evidences indicating that the alteration of proteins is implicated in the antimicrobial effects of the ITCs, there is scarce information about the effects of ITCs on specific microbial proteins or enzymes involved in the metabolic functions of microorganisms. To the best of our knowledge, the only work detailing the effects of ITCs on the microbial metabolic functions was carried out by Kojima and Ogawa (1971). The authors quantified the inhibition of oxygen uptake of three yeast strains treated with allyl isothiocyanate, methyl isothiocyanate, and phenylethyl isothiocyanate. Of these, the cytochrome c oxidase was inhibited mainly by allyl isothiocyanates. Therefore, the authors suggest that the ITCs may act as uncouplers of oxidative phosphorylation, which may in turn account for the high susceptibility of strictly aerobic fungi to these compounds.

Effect of isothiocyanates on survival of papaya fungi in *in vitro* studies

Experiments carried out in our laboratory have demonstrated that ITCs efficacy for controlling papaya fungi in storage depends on their chemical structure, concentration, and the type of fungi. We observed that growth of *C. gloeosporioides* was completely inhibited by allyl ITC at all concentrations tested during the 8 d of incubation at 25°C (**Fig. 6**); the same effect was observed with benzyl ITC at concentrations up to 2 µl ml^{-1}. Other ITC that inhibited the growth of this fungus until the fifth and sixth day of incubation were phenyl ITC at 1.5 and 2 µl ml^{-1} while propyl ITC delayed mycelial growth until the fifth day of incubation. For *F. oxysporum* (**Fig. 7**), the effect of the ITC's tested was not completely inhibitory as that observed in *C. gloeosporioides*. Nevertheless, lower growth compared with the control was observed when it was held in phenyl ITC at the highest concentrations of 1.5 and 2 µl ml^{-1}. The same effect was observed with phenylethyl ITC at all concentrations. In this same study, the fungus *A. alternata* was not affected by any of the ITCs tested (data not shown). In our studies, we confirmed that conidia of the above tested fungi were more affected than the mycelia (**Table 6**). Germination of both *C. gloeosporioides* and *F. oxysporum* did not occur in the presence of any of the ITCs used while the conidia of *A. alternata* did not germinate with benzyl ITC. The spores of *R. stolonifer* were suppressed in the presence of allyl, phenyl, and propyl ITCs.

Effect of isothiocyanates on the control of fungi in papaya fruits

In preliminary experiments, we found that pretreated papayas with two different ITCs at various concentrations overall reduced infection rot during storage (**Table 7**). Papayas harvested at maturation stage treated for 24 h with allyl, and phenyl ITCs had markedly less infection than the water-

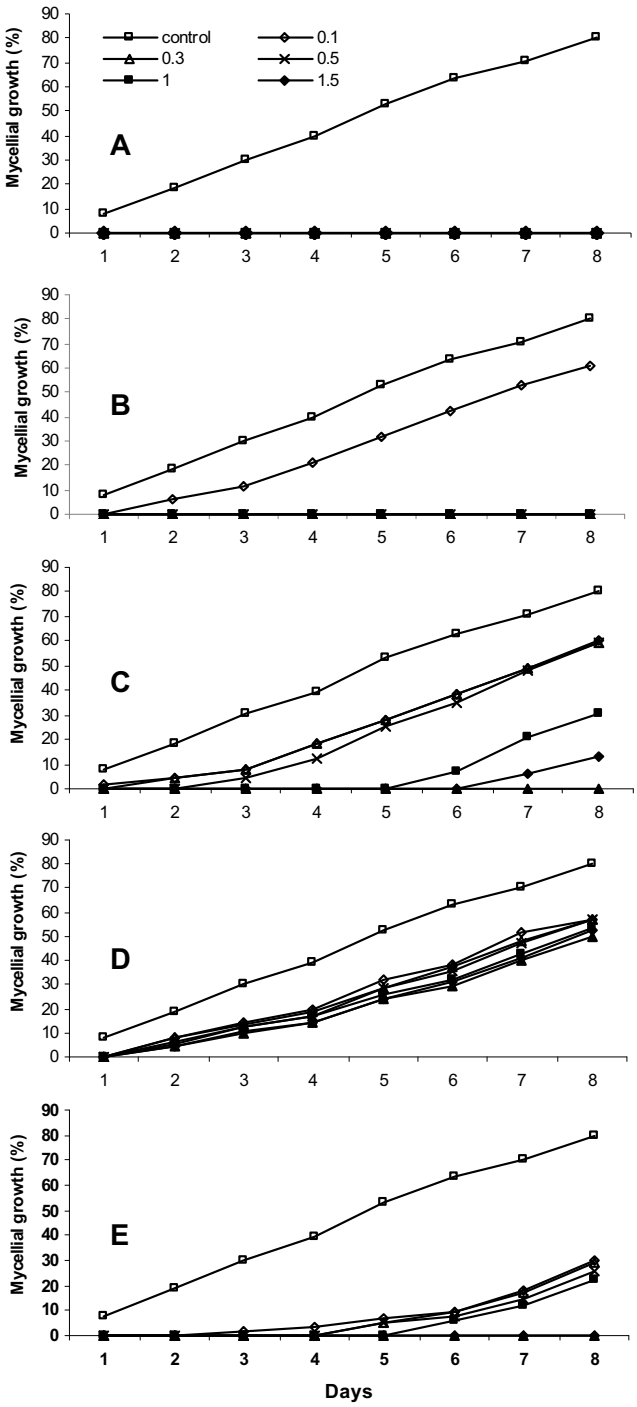

Fig. 6 Mycelial growth of *Colletotrichum gloeosporioides* incubated for 8 days in different isothiocyanates at various concentrations. (**A**) Allyl, (**B**) benzyl, (**C**) phenyl, (**D**) phenlethyl, (**E**) propyl.

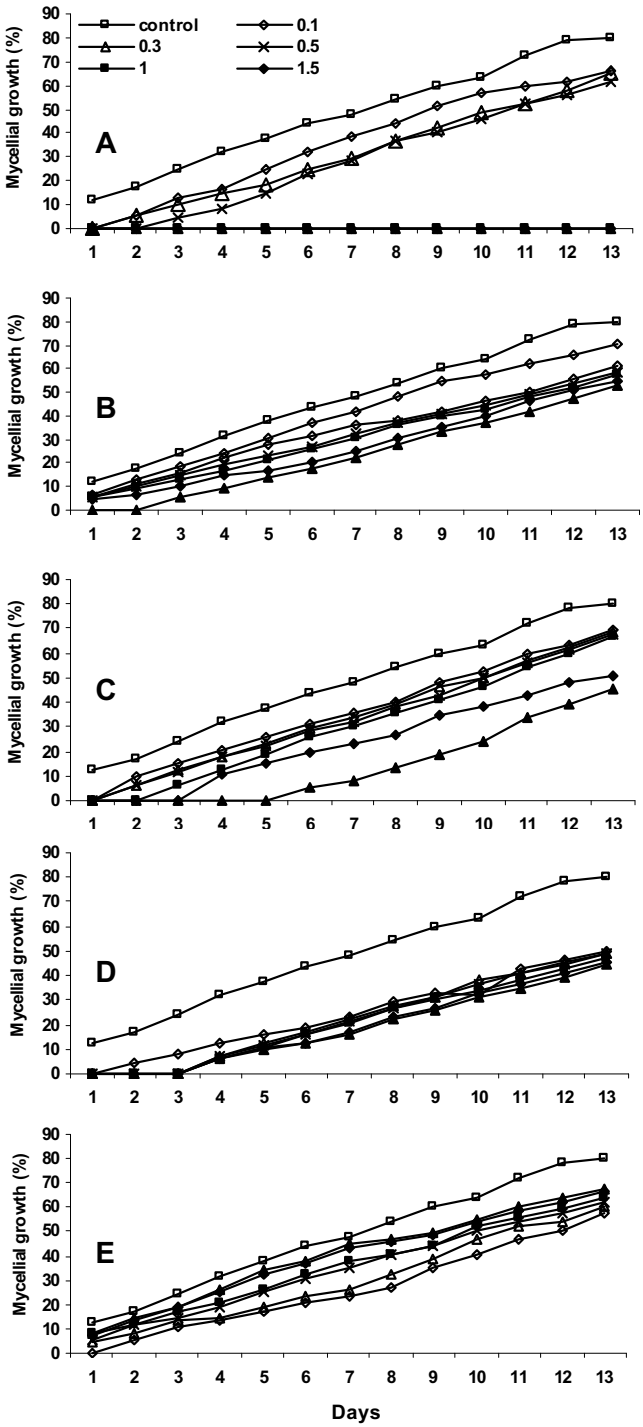

Fig. 7 Mycelial growth of *Fusarium oxysporum* incubated for 13 days in different isothiocyanates at various concentrations. (**A**) Allyl, (**B**) benzyl, (**C**) phenyl, (**D**) phenlethyl, (**E**) propyl.

treated ones. The lowest infection (17%) was observed in papayas treated with allyl ITC at a concentration of 1.0 µl ml^{-1} (**Fig. 8**). However, the fruits treated with phenyl ITC at 0.5, 1.0, and 2.0 µl ml^{-1} had showed control similar to that achieved with fungicides. Papayas treated at the highest concentration of benzyl ITC (2.0 µl ml^{-1}) showed a percentage infection of 33%.

CONCLUSIONS

As we have seen in the last few years, postharvest rot incidence in various fruits, including papayas, has seriously increased. Storage rot of papaya is still one of the major problems associated with marketing of high-quality fruits at the wholesale and retails levels in Mexico. Overall, a similar problem is reported in other papaya production areas worldwide. The main fungi causing deterioration on this fruit are *C. gloeosporioides*, *F. oxysporum* and *R. stolonifer*, among others. Papaya growers and handlers have observed that application of synthetic fungicides is no longer efficient in controlling fungal growth. In addition, the use of chemicals is a practice not quite encouraged among growers who target the export markets. The results we have obtained indicate that chitosan and isothiocyanates might be effective in controlling postharvest fungi in papaya. We have done both *in vitro* and *in situ* experiments. In both cases we have obtained significant evidence to recommend further studies on these two natural compounds. Nonetheless, there is still much substantial research to do. The inclusion of these two compounds in laboratory and semi-commercial levels would point to the feasibility of having an integrated method. To our knowledge several brands of commercial chitosan are now in the market. We still do not know their efficacy in controlling rots in papaya.

Table 6 Germination of conidia of various fungal strains isolated from infected papayas, using different types of isothiocyanates at various concentrations.

Isothiocyanates and concentrations (µl ml^{-1})	Percentage germination			
	A. alternata	*C. gloeosporioides*	*F. oxysporum*	*R. stolonifer*
Allyl				
0.1	90.6	0	0	0
0.3	89.5	0	0	0
0.5	87.5	0	0	0
1.0	78.0	0	0	0
1.5	76.6	0	0	0
2.0	65.9	0	0	0
Benzyl				
0.1	0	0	0	15.5
0.3	0	0	0	9.0
0.5	0	0	0	7.8
1.0	0	0	0	3.5
1.5	0	0	0	0
2.0	0	0	0	0
Phenyl				
0.1	14.5	0	0	0
0.3	16.3	0	0	0
0.5	17.1	0	0	0
1.0	22.6	0	0	0
1.5	25.4	0	0	0
2.0	32.3	0	0	0
Phenylethyl				
0.1	54.7	0	0	82.2
0.3	59.0	0	0	66.1
0.5	64.7	0	0	64.8
1.0	65.4	0	0	60.3
1.5	66.6	0	0	31.3
2.0	67.4	0	0	23.3
Propyl				
0.1	100	0	0	0
0.3	100	0	0	0
0.5	100	0	0	0
1.0	100	0	0	0
1.5	100	0	0	0
2.0	100	0	0	0
Control	100	100	100	100

Table 7 Percentage infection and disease severity of naturally infected papaya fruits treated for 24 h with three different isothiocyanates at various concentrations before storage at 25°C.

Treatment	Percentage infection	Severity index*
Allyl isothiocyanate (µl ml^{-1})		
0.5	33	1.6
1.0	17	1.4
2.0	30	1.5
Benzyl isothiocyanate (µl ml^{-1})		
0.5	57	1.8
1.0	53	1.8
2.0	33	1.5
Phenyl isothiocyanate (µl ml^{-1})		
0.5	20	1.4
1.0	23	1.4
2.0	23	1.3
Water	57	1.8
Fungicide (Benlate®)	20	1.3

*Severity index: 1=0%, 2=2-25% of the surface fruit rotten.

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Fig. 8 Postharvest rot after 5-d storage at ambient temperature in papayas pretreated with allyl ITC for 24 h and those untreated.

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