

THE COST AND EFFECTIVENESS OF PRE-HARVEST INTERVENTIONS IN BEEF CATTLE

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ABSTRACT

Because cattle have been identified as a reservoir for foodborne pathogens, interest has grown in developing interventions to reduce levels of pathogens at the producer level (pre-harvest). Several pre-harvest interventions have been identified as potentially effective for reducing pathogen levels in animals, yet no comparative research has been done comparing the cost and effectiveness of different interventions. This article provides a current assessment of existing interventions for their effectiveness and economic costs and suggests where additional evaluation is needed to continue to improve pre-harvest food safety in the beef industry.

KEYWORDS: pre-harvest food safety, *Escherichia coli* O157, cattle, economics.

INTRODUCTION

Deaths and illnesses from foodborne illness have a major impact on the economic and public health of the United States. More than 200 illnesses are transmitted through food and the Centers for Disease Control (CDC) estimates that “76 million illnesses, 325,000 hospitalizations, and 5,000 deaths” are caused by foodborne disease in the each year (Mead et al, 1999). What is more, new information suggests that these estimates may be low due to previously unknown long-term mortality rates associated with foodborne illness (Helms et al, 2003). While food safety is an obvious public health threat, it also has economic consequences. The United States Department of Agriculture (USDA) estimates that losses from foodborne illness cost society approximately \$6.9 billion per year due to medical costs and lower productivity alone (Crutchfield and Roberts, 2000). In addition, executives of the top beef processing companies in the United States have identified food safety as the number one challenge facing the beef industry today (Ledbetter, 2002). John Simons, President and CEO of Swift & Co., summarized the industry’s concern at the Texas Cattle Feeders Association annual meeting in 2002, when he said, “None of us wants, or can afford, more frequent and larger recalls.” (Ledbetter, 2002) Recalls and outbreaks have a devastating impact on the beef production and processing industry as well as on the consumers who become ill due to contaminated product.

In attempting to reduce the prevalence of foodborne illness in the United States, scientists, government officials, food producers and processors have sought to implement a comprehensive “farm to table” approach to food safety. Such an approach operates under the theory that each component part of the food production chain has responsibilities in ensuring safe, wholesome food. Yet efforts to reduce contamination in the beef products have primarily focused on the post-harvest stage of production and cattle producers have had little involvement. Nevertheless, live animals play a significant role in the contamination of beef products. Live cattle have been identified as a reservoir for several foodborne pathogens including *Escherichia coli* (*E. coli*) O157:H7, *Salmonella* spp., and *Campylobacter* spp. (USDA 1994). These pathogens can enter the food supply during slaughter from transmission from the hide, workers or machinery in the processing environment, or by direct contact with feces or digesta from the intestinal tract (Elder et al, 2002). Moreover, a positive correlation has been found between positive fecal and hide samples for *E. coli* O157:H7 taken from cattle and subsequent contamination of the carcasses. (Elder et al 2000) Because the potential for direct contamination of the carcass from the animal exists, scientists are looking at ways to reduce, control, or eliminate foodborne pathogens prior to harvest. Decreasing the level of pathogens in the live animal should decrease the occurrence of the pathogen in the food supply and reduce the risk of food-borne illness to consumer (Jordan et al, 1999). Although research in the area of pre-harvest food safety is in its early stages, studies have suggested several interventions have potential to consistently reduce pathogens in the live animal. Nevertheless, while previous studies have addressed the potential effectiveness of individual interventions, little or no comparative research on interventions or the cost associated with the interventions is available.

While microbiological effectiveness in reducing pathogens is the primary goal when developing pre-harvest interventions, the economic and practical concerns of producers must also be considered. In order to achieve the most effective and efficient use of pre-harvest interventions, questions about the cost, effectiveness, and external effects of different interventions will need to be addressed. The objective of this paper is to provide a review of the effectiveness and economic costs of several potential pre-harvest interventions to be used in cattle production. Table 1 provides a summary of these interventions, including the name, description, effectiveness, and associated economic costs associated, while more detailed information follows below.

PRE-HARVEST INTERVENTIONS

Dietary Changes/Feed Supplements

Fiber

Using increased amounts of fiber or roughage in cattle diets as a means of reducing foodborne pathogens has been subject to controversy due to conflicting reports about its effectiveness. Scientists have speculated that levels of *E. coli* O157:H7 are related to the ruminal pH and the volatile fatty acid (VFA) content in the gastrointestinal tract. Diets with increased hay or roughage result in an increased ruminal pH and a decrease in VFA concentration, whereas high-concentrate (grain) diets result in the

TABLE 1. PRE-HARVEST INTERVENTIONS.				
NAME	DESCRIPTION	INHIBITORY EFFECT ON E. COLI O157:H7	ECONOMIC COSTS	CURRENTLY AVAILABLE
I. DIETARY CHANGES/FEED SUPPLEMENTS				
Fiber	Using increased amounts of fiber in cattle diets.	Unknown. Inconsistent reports on its effectiveness make it difficult to state whether there is any inhibitory effect at this time.	Too impractical to implement on a wide-scale basis. Requires extra time on feed and may see decreased animal performance.	Yes.
Whole Cottonseed	Whole cottonseed is substituted in concentrate to feed at a rate 10 to 15% dry matter.	Unknown. Young dairy calves fed whole cottonseed have been found to be less likely to carry E. coli O157:H7. Preliminary data have shown similar results in feedlot cattle.	Unknown. Prices may vary significantly due to volatility of price due to seasonal and geographic variation, and potential external costs are still being studied.	Yes.
Probiotics / Direct Fed Microbials	Bacterial organisms which maintain proper balance and health in the digestive system and help fight illness and disease.	Supplementing cattle diet with a Lactobacillus-based direct fed microbial has been shown to reduce the prevalence of E.coli O157:H7 by approximately 50%.	Estimated at approximately 1.5 – 2.0¢ head/day on feed, depending on the size of the operation. At 160-170 days, approximate \$2.40 to \$3.40 per head.	Yes. Currently FDA-approved as a feed supplement in cattle to improve performance.
Tasco	A commercially available feed supplement derived from brown seaweed.	Supplementing Tasco-14 at 2% during the final two weeks of the feeding period has reduced pathogenic E. coli in the feces and on the hides of cattle at harvest.	14-day feeding before slaughter was estimated at \$3.75 to \$4.25 per head.	Yes. Currently FDA-approved as a feed supplement in cattle.
Bacteriophage	Viruses which can infect and kill harmful bacterial cells.	Studies have shown that contamination of E. coli O157:H7 has been reduced by feeding O157-specific bacteriophages after inoculation with the pathogen.	Unknown. Direct cost of treatment are estimated to be low (< \$1.00 per head) as it is likely be used only as a one-time treatment before slaughter.	No. Currently not FDA-approved for use in human food.
Sodium Chlorate	When ingested, sodium chlorate has a bactericidal effect on E. coli O157:H7	Orally administering sodium chlorate to cattle inoculated with E. coli O157:H7 significantly reduced the amount of the pathogen in the feces.	Unknown. Direct cost of treatment estimated at 30¢ per animal.	No. Currently not FDA-approved for use on animals which will be slaughtered for food.

opposite (Magnuson et al, 2000; Owens and Goetsh, 1988). Yet the results from studies increasing the amount of fiber in cattle diets have not been consistent.

Early studies reported that feeding sheep diets high in fiber resulted in large amounts of shedding of *E. coli* O157:H7 in experimentally inoculated animals, while shedding was decreased in animals fed a high-nutrient diet consisting of corn and pelleted alfalfa (Kudva, Hatfield and Hovde, 1995; Kudva et al, 1997). One study that examined the shedding of *E. coli* O157:H7 found that hay-fed cattle shed the pathogen for longer periods (39 to 42 days) than those fed a concentrate diet (4 days) (Hovde, 1999). Other studies, however, reported no relationship between diet and the ruminal presence of *E. coli* O157:H7 (Magnuson et al, 2000; Tkalcic et al, 2000). For example, Magnuson et. al reported that there were no differences in the shedding of *E. coli* O157:H7 in heifers fed growing diets (typically lower concentrate) or finishing diets.

Finally, still other studies have reported that the amount of acid-tolerant *E. coli* shed by cattle fed hay was less than those fed a concentrate diet (Diez-Gonzalez, 1998). In fact, a recent study found that although low levels of fiber in sheep diets increased shedding, while higher levels decreased shedding. Normal concentrate diets consisting of approximately 5% acid detergent fiber increased fecal shedding in lambs, while increasing the percentages to rates between 10% and 20% decreased fecal shedding without adversely affecting performance (Lema et al, 2002).

Nevertheless, even if increased hay or roughage in the diet was found to be significant in reducing levels of pathogens, questions regarding cost, practicality, and marketing currently limit its use. While grass-fed beef may be a positive niche market for some producers, it is not considered economically feasible for the industry as a whole (Callaway et al, 2003). Finishing cattle on a non-concentrate diet requires additional time and has been reported to decrease performance and marketability. Grass-fed, or forage finished cattle have also been reported to have a lower dressing percentage, higher shrinkage, and lower quality grade (Schroeder et al, 1980). Additionally, grass-fed beef has been reported to be more variable in flavor and color and less appealing to consumers due to the different flavor and deterioration during retail display (Schroeder et al, 1980).

Whole Cottonseed

Similar to increased fiber in cattle diets, the inhibitory effects of whole cottonseed on shedding of *E. coli* O157:H7, has not been clearly established. Some studies have reported a negative association (Garber et al, 1995, Hancock et al, 1994), while others have reported finding no association (Buchko et al, 2000; Dargatz et al, 1997). A recent preliminary data from Texas Tech University, however, indicated that whole cottonseed may be effective in decreasing the shedding of *E. coli* O157:H7 in feedlot cattle; and a large-scale study is currently underway (Younts-Dahl et al, 2003).

If whole cottonseed is proven as effective intervention, it may some unique advantages for producers. Whole cottonseed has long been an important feed ingredient in the dairy industry, particularly in the Western U.S. Often fed at a concentration of 10 to 15% of the dietary dry matter, whole cottonseed is an excellent source of protein, fat, and digestible fiber. Whole cottonseed (with lint) typically contains 23.5% crude protein, 19.3% ether extract (fat), and approximately 50% neutral detergent fiber (Council, 2001). Although less frequently used in the feedlot beef cattle industry, whole cottonseed can be

used effectively in high-concentrate finishing diets of beef cattle (Zinn and Plascencia, 1993), potentially replacing all supplemental fat.

Finally, with regard to cost, depending on two important variables, whole cottonseed may be an economical intervention for producers. First, while whole cottonseed has advantage over other feeds in that it does not require any processing before being fed to cattle, seasonal and geographic differences can cause its price to vary widely. Second, depending on the availability of other nutrients, whole cottonseed may not always be the most economical option for producers' nutritional needs (Rodgers, Poore and Paschal, 2002).

Probiotics/Direct-Fed Microbials

The inhibitory effect of probiotics or direct-fed microbials (DFMs) such as lactic acid bacteria on pathogens has been known for many years. The inhibition occurs in vitro during both growth and refrigerated storage and has been documented in various food products. Direct-fed microbials are already used in the poultry industry to inhibit *Salmonella* and several studies have confirmed the potential for DFM to decrease the shedding of *E. coli* O157:H7 and other pathogens in cattle.

Zhao et al. reported that probiotic organisms (*Proteus mirabilis* and non-pathogenic *E. coli*) reduced the duration of shedding of *E. coli* O157:H7 in calves (Zhao et al, 1998). Those fed the probiotics shed the pathogen for 9 to 17 days, whereas the controls shed the pathogen for up to 32 d.

Researchers at Texas Tech University evaluated the effect that dietary supplementation with a *Lactobacillus*-based DFM had on fecal shedding of *E. coli* O157:H7, prevalence of *E. coli* O157:H7 in pens, on carcasses, and on hides, and cattle performance (Brashears, Jaroni and Trimbleb, 2003). The study consisted of a feeding trial using 180 beef steers that were evaluated for shedding of *E. coli* O157:H7 at feedlot arrival, just before supplementation with the DFM, and every fourteen days thereafter until slaughter. *Lactobacillus acidophilus* strain NPC 747 decreased shedding of *E. coli* O157 in the feces of individual cattle during the feeding period. *E. coli* O157 was approximately twice more likely to be detected in control samples than in samples from cattle receiving supplementation with the DFM, and the number of positive hide samples at harvest and the number of pens testing positive for the pathogen, were decreased.

Even so, these results were not achieved at the expense of performance. Body weight gain (live or carcass basis) and feed intake during the DFM supplementation period did not differ among treatments. Gain efficiency on a live-weight basis did not differ among treatments, but carcass-based gain efficiency was improved for the two DFM treatments compared with the control. These results suggest that feeding DFM to cattle will decrease fecal shedding of *E. coli* O157, as well as contamination on hides, without detrimental effects on performance.

The cost of this intervention ranges from approximately 1.5 to 2.0 cents per head per day, depending on the size of the feeding operation (Ware, 2003). Thus, for a feeding period of 160-170 days, the cost would range between \$2.40 and \$3.40 per head, indicating that this may be an economical and effective pre-harvest intervention.

Tasco

Tasco is a commercially produced feed supplement derived from the brown seaweed *Ascophyllum nodosum*. Although currently FDA-approved and marketed for other purposes, researchers at Texas Tech University have found that supplementing Tasco during the final 2 weeks on the feedyard has reduced pathogenic *E. coli* in the feces and on the hides of cattle at harvest (Behrends et al, 2000). The cost of feeding Tasco for a 14-day period, however, has been reported to be approximately \$3.75 to \$4.25/head (Seamann, 2003). Nevertheless, trials are currently underway to examine the effectiveness of feeding for only 7 days prior to slaughter, which would reduce the cost to \$1.75 to \$2.00/head (Seamann, 2003).

Bacteriophages

Bacteriophages are viruses that can infect and kill certain bacterial cells, and their use as an intervention to reduce pathogen levels in cattle may have some unique advantages. Bacteriophages are natural, nontoxic, have historically been used to treat human infections, and present a possible alternative to using antibiotics. Also, bacteriophages can target specific pathogens, thus reducing the risk of upsetting the normal flora of the rumen. Also, because bacteriophages are viruses, infecting a few animals with the virus could be sufficient to treat an entire herd (Randerson, 2003).

In clinical trials, enteropathogenic *E. coli* infections in mice, calves, piglets, and lambs (Smith and Huggins, 1982) have been decreased by using bacteriophage therapy. More specifically, Kudva et al. (Kudva, 1999), and Waddell et al. (Waddell, 2000), reported that bacteriophages been effective in inhibiting *E. coli* O157:H7. More recently, researchers at Evergreen College in Washington state have discovered a phage that in a small clinical trial reduced numbers of *E. coli* O157:H7 by 99 percent in just two days (Randerson, 2003).

Like antibiotics, bacteriophages would likely be used as a one time treatment before slaughter and are likely to be comparable in cost (Brabban, 2003). However, bacteriophages are currently not approved for use in human food, and before gaining FDA-approval, more research is likely needed to prove that the viruses are not only effective, but also safe should they be passed on to humans through the food chain (USDA, 2002; Randerson, 2003).

Sodium Chlorate

Small amounts of sodium chlorate have been proven to kill harmful intestinal bacteria such as *Salmonella typhimurium* and *E. coli* O157:H7. A recent study conducted by found that administering small amounts of sodium chlorate to cattle via drinking water 24 hours before slaughter was effective in reducing the amount *E. coli* O157:H7 in the feces, but did not reduce levels of hide contamination (Callaway et al, 2002).

In large amounts, sodium chlorate is toxic to cattle and is not yet approved for use in cattle for human consumption. According to a recent USDA report, however, “the [FDA] is currently considering whether sodium chlorate is generally recognized as safe (GRAS), or whether it should be regulated as a food additive, feed additive or a drug,” (USDA, 2002). Moreover, additional studies on performance, meat quality, and residue may be needed. Due to these uncertainties, it is currently unknown what the economic costs of this intervention will ultimately be, although one report estimates the direct cost

of the treatment at 30 cents per animal (Duckworth, 2001) thus indicating this could be a cost effective intervention.

Medicines

Vaccination

Although still in commercial development, vaccination may be an effective intervention strategy for decreasing *E. coli* O157:H7 in cattle. While not expected to be 100% effective in reducing or eliminating levels of *E. coli* O157:H7, a vaccine may significantly reduce the amount of infection in cattle or reduce the number of days that the animals shed the pathogen. Potter and Finlay reported that two separate vaccinations decreased fecal shedding of the pathogen by cattle, possibly by preventing adherence of the organism to the gastro-intestinal tract (Potter and Finlay, 2000). Because a vaccine is not expected to be commercially available until at least February 2004 (Bradford, 2003), the price of such a vaccine is not known for certain. However, if it falls within the current price range for other bovine vaccines, it would only cost about \$1 to \$2 per head (Potter, 2003).

TABLE 1. PRE-HARVEST INTERVENTIONS (Continued).				
NAME	DESCRIPTION	INHIBITORY EFFECT ON <i>E. COLI</i> O157:H7	ECONOMIC COSTS	CURRENTLY AVAILABLE
II. Medicines				
Vaccination	Vaccines produce antibodies that prevent adherence and colonization of pathogens in the digestive tracts of cattle.	While not a 100% barrier to the pathogen, it may reduce the amount of infection in cattle or reduce the number of days that the animals carry the pathogen. Field trials are currently underway in Canada.	Anticipated to cost between \$1.00 to \$2.00 per head.	No. Not likely to be approved and available for commercial use for until at least February 2004
Neomycin Sulfate	Broad spectrum antibiotic.	Oral administration of therapeutic amounts reduced <i>E. coli</i> O157:H7 to non-detectable levels in naturally infected cattle.	Direct cost of the treatment has been estimated at approximately \$1.34 per head, not including handling costs	No. Current regulations only allow for use on cattle which are suffering from bacterial enteritis, and should not be universally administered.

Neomycin Sulfate

Neomycin sulfate is a broad spectrum antibiotic used to treat cattle. Elder et. al. (Elder et al, 2000) recently reported that orally administering therapeutic levels of the antibiotic significantly reduced levels of *E. coli* O157:H7 in naturally-infected cattle and lowered total numbers of generic *E. coli*. Nevertheless, even if proven effective, the potential for widespread use of neomycin sulfate in the industry may be limited due to concerns about antibiotic resistance and cost. Concerns about antibiotic resistance recently led McDonald's to announce a new policy to encourage its suppliers to reduce antibiotic use (McDonald's, 2003). Additionally, current FDA regulations only permit the use of neomycin sulfate "[f]or the treatment and control of colibacillosis (bacterial enteritis) caused by *Escherichia coli* susceptible to neomycin sulfate in cattle (excluding veal calves), swine and goats[.]" and does not specifically allow for the use of neomycin to reduce levels of *E. coli* O157:H7.

Moreover, even if neomycin is ultimately approved for reducing levels of *E. coli* O157:H7, one report speculated that neomycin may be too expensive to administer universally, but may be cost-effective for "high risk cattle two days before slaughter." (Maday, 2002). Nevertheless, for a 1200-pound steer the cost of the treatment (minus any handling costs) has been estimated at only \$1.34 per head. (Keen, 2003)

Management Practices

To date no specific sanitation or management practices have been proven that are effective at reducing the levels of foodborne pathogens prior to harvest. Certain

TABLE 1. PRE-HARVEST INTERVENTIONS (Continued).

NAME	DESCRIPTION	INHIBITORY EFFECT ON <i>E. COLI</i> O157:H7	ECONOMIC COSTS	CURRENTLY AVAILABLE
III. Management Practices				
Best Management Practices	The USDA is currently working on a list of specific management practices for producers to follow to help reduce pathogen loads on animals.	Unknown. While individual impacts of management practices may be too small to notice, their aggregate effect may be significant.	Unknown. May be very inexpensive for simple sanitation practices, but major changes to management practices or facilities could be expensive.	No. A list of best management practices is still under development.
Cattle Cleanliness	Practices relating to keeping mud, tag, and feces off the animals before slaughter.	While the actual amount of reduction is not known, scientists have found a positive correlation between hide contamination and carcass contamination.	Unknown. Costs may vary significantly due to variations in geography, facilities and season.	Yes, as long as the methods used to keep the cattle clean do not violate state or federal laws and regulations.

factors, however, such as the conditions of pens and presence of pathogens in the water troughs may lead to an increase in higher prevalence of infected animals (Lejeune, Besser and Hancock, 2001; Smith et al, 2001). Because of this potential for an increase in pathogens, the USDA's Food Safety Inspection Service is developing a list of best management practices that may help reduce foodborne pathogens before slaughter (USDA, 2003). One management practice that has already gained attention as a way to increase safety before slaughter is cattle cleanliness. Manure on the hides of animals has been identified as a source of contamination of beef products during slaughter (Hancock et al, 1999), and levels of carcass contamination have been found to be associated with levels of physical contaminants such as mud or feces on the hide (Elder et al, 2000). Therefore, if these contaminants can be removed before slaughter, it should in turn reduce the probability of contamination of the final product. One processing company in Alberta, Canada, has already taken this to heart. It recently devised a system that scores the levels of tag, mud and manure on the animals, and awards those producers that consistently provide the cleanest animals (Cargill, 2003).

TABLE 1. PRE-HARVEST INTERVENTIONS (Continued)

NAME	DESCRIPTION	INHIBITORY EFFECT ON <i>E. COLI</i> O157:H7	ECONOMIC COSTS	CURRENTLY AVAILABLE
IV. Other				
Multiple Interventions	Using two or more interventions at a time.	Using direct fed microbials, neomycin sulfate, and a bacterial vaccine together was shown to be more effective in reducing the number of animals shedding <i>E. coli</i> O157:H7 in their feces or carrying it on their hides than most single interventions.	Using all three of the interventions in concert is estimated to likely exceed \$7.00/head.	No. See above comments on Neomycin and vaccines.

FUTURE IMPLICATIONS FOR PRE-HARVEST FOOD SAFETY RESEARCH

This paper examined the current state of knowledge regarding the potential for pre-harvest interventions to effectively and efficiently reduce foodborne pathogens. Because many pre-harvest interventions are still in development (or not FDA-approved for use in food production) specific data about economic costs of interventions were not always available. Also, because of the differences in study design and measures of effectiveness,

direct comparison of the effectiveness of the interventions was not possible. For example, some studies inoculated only a few animals and measured the levels of *E. coli* O157:H7 following treatment. In contrast, other studies used naturally-infected animals and measured the number of animals that tested positive for shedding the pathogen in the feces or carrying it on their hides. Thus, as these interventions are developed, additional studies to directly compare their cost and effectiveness will be needed.

In addition to evaluating individual interventions, more research is needed on using two or more interventions in concert. Most studies to date have only considered the effectiveness of utilizing single interventions. Yet using two or more interventions in concert or as separate treatments is likely to be more effective. Utilizing a stochastic model of the effects of pre-harvest interventions, Jordan and McEwen initially found that using a vaccine and a feed supplement to reduce the amount of pathogens in the feces would be more effective than using them individually (Jordan et al, 1999). More recently, researchers at Colorado State University found that utilizing a direct-fed microbial (*Lactobacillus acidophilus*), neomycin sulfate, and a bacterial vaccine in combinations generally resulted in lower numbers of animals shedding *E. coli* O157:H7 or carrying it on their hides than were found using a single intervention (Roybal, 2003). This “multiple-hurdle” approach to pathogen reduction works under the presumption that although no individual intervention will be 100% effective, implementing multiple interventions at various steps throughout the chain will have an additive effect of reducing the probability of contamination of the final product. Such an approach has already been successfully utilized in processing plants as an integral part of their hazard analysis critical control point (HACCP) plans (Bacon et al, 2000).

More research is also needed into how of pre-harvest food safety is to be incorporated into a system-wide, multiple hurdle approach to controlling foodborne pathogens in the food chain. The prevalence of foodborne pathogens in live animals, their feces, and on their hides suggests that they are major source of contamination, and scientists expect that increases in safety at the pre-harvest stage will ultimately result in fewer foodborne illnesses. Nevertheless, while pre-harvest food safety interventions are likely to reduce the probability of contamination of the final product, the amount of any such reduction of is yet unknown. Although significant progress has been made, we do not yet fully understand the epidemiology of how foodborne pathogens move throughout the food chain. Gaining an understanding of the ultimate impact of pre-harvest food safety interventions on the number of foodborne illnesses is critical for determining where to focus our food safety efforts in the future.

In conclusion, although pre-harvest food safety interventions in beef cattle are still in the early stages of development, several possibilities for safe, effective, and practical interventions clearly exist. Still, more information is needed on the cost and effectiveness of these interventions as well as the overall impact on the rest of the production chain in order to most effectively and efficiently protect the safety of our food supply.

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