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Economic Loss, Amount of Beef Discarded, Natural Resources Wastage, and Environmental Impact Due to Beef Discoloration

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Abstract: Any deviation from a bright-red color leads to a discounted price or beef is discarded. Limited data are currently available on the economic losses due to retail beef discoloration. Therefore, the objective of the study was to estimate economic losses, the amount of beef discarded, natural resource wastage, and environmental impact due to beef discoloration. One-year data of total beef sales, total beef discarded, and discounted sale values were collected from 2 national retail chains and 1 regional retail chain located in the Southern United States, representing data from 5,034 stores and 44 states. The US beef system life cycle parameters from published literature were used to calculate the impact of discarded meat on water and energy use and greenhouse gas emissions. The study noted that approximately 2.55% of beef is discarded because of discoloration. The results indicate that the US beef industry loses $3.73 billion annually owing to discoloration. The total amount of beef discarded per year in the US corresponds to 194.70 million kg, which represents wasting 780,000 animals and the associated natural resources used in their production. A 1% decrease in discolored beef in the US could reduce natural resource waste and environmental impact by 23.95 billion L of water, 96.88 billion MJ of energy consumed, and 0.40 million tons of carbon dioxide equivalent emission along the beef upstream value chain. Therefore, improving the color stability of meat could increase the sustainability of beef production and limit the waste of nutritious beef, so the application of novel technologies to mitigate color deterioration should be imperative.

Key words: sustainability, beef color, economic loss, water, energy, emissions
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Introduction

The amount of food loss and waste along the food supply chain has become a compelling issue stirring up concern from stakeholders in the food system and policymakers (Muth et al., 2019). Forty percent of food produced is lost or wasted annually, costing the food industry $218 billion (Gunders, 2017). After harvest, various food products decrease in quality at a different rate depending on chemical composition (Hammond et al., 2015). Visual perception plays an important role in consumer perception of quality. For example, beef color is an important quality attribute that consumers associate with freshness and wholesomeness; however, beef is a highly perishable product owing to its greater water content and nutrient-dense matrix (Mancini and Hunt, 2005; Ramanathan et al., 2020, 2021). Therefore, deviations from a preferred bright cherry-red color result in the meat being discarded or discounted initially and ultimately discarded if it is not successfully marketed, depending on the extent of discoloration and individual retailers' protocols (Van den Oord and Wesdorp,

1971; Cornforth, 1994; Mancini and Hunt, 2005; American Meat Science Association, 2012).

Compared with other species of food animals, cattle require a longer time to reach market age. Although cattle are often described as protein upcyclers (i.e., converting inedible human feed to nutrient-rich beef), this process requires natural resources and energy to produce and market beef. Hence, efficient utilization of water, feed, and energy needed to produce beef are critical for a sustainable animal industry. Given the complexity of meat marketing, an accurate determination of economic loss can be challenging. Most of the economic losses due to discoloration are based on educated guesses or extrapolation of available data (Smith et al., 2000). For example, Sherbeck et al. (1995) reported that between 2% and 20% of meat is discounted or discarded owing to loss of bright-red color. A previous report by Smith and others in 2000 noted that the US beef industry lost $1 billion annually because of discoloration (Smith et al., 2000). Since 2000, the meat industry has adopted several practices, including case-ready meat, to enhance efficiency in meat merchandise (McMillin, 2008). However, limited data are currently available on the economic losses due to retail beef discoloration. Therefore, the objective of the study was to determine economic losses, the amount of beef discarded or sold at a discount, natural resource wastage, and carbon emission due to beef discoloration.

Materials and Methods

Data

One-year data of total beef sales, total beef discarded, and discounted sale values during 2020 were collected from 2 national retail chains and 1 regional retail chain. The 2 national retail chains were located throughout the US and represent the largest retail chain in the US, and the 1 regional retail chain was located in the Southern US. The data collected in the study came from 5,034 stores and 44 states (the first national retail chain: 4,473 stores; the second national retail chain: 553 stores; and the regional retail chain: 8 stores). Due to the nondisclosure agreement, the names of the retail chains are not included. All data were collected from meat store managers and front-line staff. No consumer data were collected. The 2 retail chain stores utilize case-ready meat type of retailing, whereas the third retail store uses traditional polyvinyl chloride overwrap packaging with Styrofoam® trays. The data for ground beef and steaks (strip steak [*longissimus lumborum*, Institutional Meat Purchasing Specification [IMPS] #1180]; ribeye steak [*longissimus dorsi*, IMPS #1112]; tenderloin steak [*psoas major*, IMPS #1189]; inside round [*semimembranosus*, IMPS #1169]; and shoulder clod steak [*triceps brachii*, *teres major*, *infraspinatus*, IMPS #1114]) were collected for 1 y. The steaks in this manuscript denote a pool of steaks from different cuts. The data include the total amount of beef sold, the amount of beef discarded, and the sales discount. To avoid disclosure of the retailer and retail chain information, we label them "Retailer A," "Retail Chain B," and "Retail Chain C." Each retailer used their own criteria to determine discoloration and discounted price.

Details about total retail sales from the US Department of Agriculture Economic Research Service database were used to assess the economic impact and estimate the amount of discolored beef discarded at the national level (USDA Economic Research Service, 2021). In order to translate the amount of beef discarded to the number of animals wasted, the total amount of beef discarded was divided by 249.7 kg (assuming 249.7 kg of boneless beef from a 635.6 kg live weight cattle and 63% dressing percentage).

Impact of beef discarded on environment

Environmental life cycle analysis is useful in understanding the impact of meat discarded due to discoloration on resource consumption and greenhouse gas emissions along the upstream and downstream pathways of the beef supply chain. For each retail store, the loss of energy and water (Table 1) at each phase of the beef supply chain supporting the retail stores was calculated as follows:

$$Loss\ of\ energy = discarded\ meat\ amount \times energy\ footprint \quad (1)$$

$$Loss\ of\ water = discarded\ meat\ amount \times water\ footprint \quad (2)$$

The values reported in Asem-Hiablie et al. (2019) were used to calculate the energy and water footprint required to produce 1 kg of boneless beef. This includes energy and water use during feed production, cow-calf operation, finishing, packing, and case ready. The energy footprint is measured by cumulative energy demand at the production stage. Cumulative energy demand is the energy used in production, production disposal, and waste materials per kg of boneless beef consumed in the US. The water footprint is measured using consumptive water use; the lost water from watershed through evaporation, absorption into

Table 1. Water, energy, and greenhouse gas footprint in beef supply chain

Resource and environmental footprint[1]	Unit[2]	Phase				
		Feed	Cow-calf	Finish	Packing	Case ready
Energy footprint: Cumulative energy demand[3]	MJ/CB	988	11.6	6	11.4	8.3
Water footprint: Consumptive water use[4]	L eq/CB	2,506	11.9	11.2	3.7	1.9
GWP[5]	kg CO_2e/CB	7.42	28.51	6.39	0.55	0.27

[1]There are more natural resources and environmental impacts measured in the research of Asem-Hiablie et al. (2019). We only considered energy, water, and emission in this paper.

[2]One unit of consumer benefit is equivalent to 1 kg of consumed, boneless, edible beef in the US.

[3]Cumulative energy demand includes the energy required in production, product disposal, and the energy content of the disposed product.

[4]Consumptive water use is lost water from watershed through evaporation, absorption into products and waste, or transferred from the watershed.

[5]Global warming potential reflects the emission level of anthropogenic CO_2, CH_4, N_2O, and halocarbons.

Source: Asem-Hiablie et al. (2019).

CB = consumer benefit; CH_4 = methane; CO_2 = carbon dioxide; CO_2e = carbon dioxide equivalent; GWP = global warming potential; L eq = liters of consumptive water to produce 1 kg boneless beef; N_2O = nitrous oxide.

products, and waste; or the lost water transferred from the watershed.

Greenhouse gas emission was measured using a carbon dioxide equivalent (CO_2e), calculated with the Global Warming Potential (GWP) index (Table 2) (Asem-Hiablie et al., 2019). The GWP is the heat absorbed by any greenhouse gas in the atmosphere, as a multiple of the heat that could be absorbed by the same mass of CO_2. The total CO_2e emission of wasted meat was calculated using Equation 3.

$$CO_2e = discarded\ meat\ amount \times GWP \quad (3)$$

Water, energy, and emission footprint parameters used in this research are presented in Table 2. We calculated energy and water that could have been saved and emissions that could have been reduced from 1% decrease on meat discoloration using the following equations (Equations 4–6).

$$Energy\ saved = reduced\ discarded\ meat\ amount \times energy\ footprint \quad (4)$$

$$Water\ saved = reduced\ discarded\ meat\ amount \times water\ footprint \quad (5)$$

$$Reduced\ CO_2e = reduced\ discarded\ meat\ amount \times GWP \quad (6)$$

Results and Discussion

The total beef sales (steaks and ground beef) from 2 major retail chains and 1 retail store for the 1-y period was approximately 528.1 million kg (Table 2). The total amount of retail beef in the US during 2020

Table 2. Summary of 52-wk data of beef sales, beef discarded, and discounted sale value collected from 2 national retail chains and 1 retail store

Retailer[1]	Product	Sales (kg)	Weight[2]	Total meat discarded (kg)	Percentage discarded	Percentage sales discounted	Discount per kg
Retailer A	Ground beef	1,676,483	0.32%	24,309	1.45%	14.00%	$1.47
	Steak	1,593,134	0.30%	48,113	3.02%	27.00%	$4.16
Retail Chain B	Ground beef	140,740,000	26.65%	3,799,980	2.70%	12.10%	$1.19
	Steak	167,980,000	31.81%	4,081,914	2.43%	10.10%	$1.56
Retail Chain C	Ground beef	98,518,000	18.66%	2,659,986	2.70%	12.10%	$1.19
	Steak	117,586,000	22.27%	2,872,626	2.44%	10.10%	$1.56
Total or weighted average[3]		528,093,617	100%	13,486,928	2.55%	11.07%	$1.41

[1]The data collected in the study came from 5,034 stores and 44 states (the first national retail chain: 4,473 stores; the second retail chain: 553 stores; and the regional chain: 8 stores).

[2]The weight is equal to the retailer's individual sales divided by total sales across the 2 retail chains and 1 retail store.

[3]Weighted averages for percentage discarded, percentage sales discounted, and discount per kg was calculated using the percentage sales weights as defined within the "weight" column of the table.

was 8.76 billion kg (USDA Economic Research Service, 2021). Ground beef represents 40% of sales, whereas steaks (strip, ribeye, tenderloin, inside round, and clod) represent 47.2% of total retail beef sales (Statista, 2021). The total amount of US retail beef corresponds to 7.64 million kg. The current study captures all geographical regions (44 states) and approximately 6.5% of total retail sales in the US. To the best of our knowledge, this is the first study using direct reporting of store data related to dollar loss due to discoloration and the amount of beef discarded.

In the current study, 2.55% of beef was discarded due to discoloration (Table 2). A previous study by the Food and Agriculture Organization reported that total loss from the beef supply chain from production to consumers is estimated to be 25% (percentages calculated collectively for US, Canada, Australia, and New Zealand; Gunders et al., 2012). More specifically, a 4% loss is reported during retailing and distribution. Williams et al. (1992) reported a value deterioration of 3% for the entire meat department and 5% for fresh meats. The data in Table 2 indicated that 10% to 27% of retail beef steaks and ground beef were sold at discounted prices, with a weighted average of 11.07%. Average consumers have been shown to prefer retail beef to be bright cherry-red (Hunt et al., 1999; Carpenter et al., 2001; Killinger et al., 2004; Ramanathan et al., 2020). As the meat begins to discolor, discounting is often necessary to market the product and avoid a total loss successfully, but the level of discount for discolored beef is established by each retailer, and there is no reference on the appropriate level of discount.

Economic losses due to beef discoloration

Direct losses to the retail beef industry from discolored beef arise from either the cost of selling discolored beef at a discount or from discard (total loss of revenue). Figure 1 demonstrates the 2 pathways of loss to the retail beef industry arising from discoloration as well as total loss from discoloration. Losses from discounted prices and discard are estimated at $1.18 billion and $2.55 billion, respectively, for a total loss from discoloration to the beef industry of $3.73 billion. Both discounting and discarding discolored beef represent sizable losses to the beef industry. However, the selling of discounted discolored beef provides revenue to the retailer; therefore, selling should be viewed as the more favorable alternative as opposed to discarding, which represents a total loss to the industry. Additionally, discarded discolored beef accounts for the majority of total losses due to discoloration at just under 69%. Lost revenue from the sale of discounted discolored beef accounts for the other 31%. This suggests that focusing on the minimization of

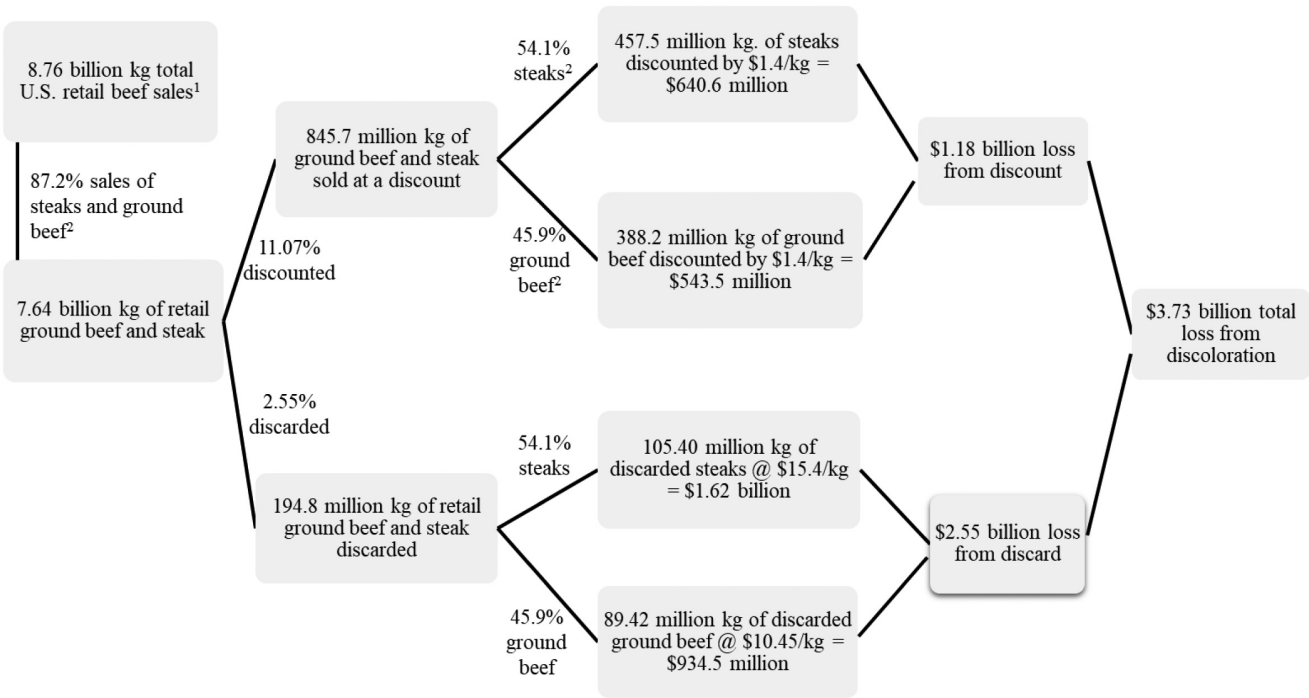

Figure 1. Estimated loss due to discoloration within the US retail beef industry. [1]Based on total retail sale in 2020; Reference: USDA Economic Research Service, 2021. [2]87.2% sales of total amount of beef contributed by steaks (47.2%) and ground beef (40%); Reference: Statista, 2021.

discarded retail beef would have the greatest marginal benefits to the retail beef industry.

Grebitus et al. (2013) evaluated consumer willingness to pay (WTP) for color attributes in ground beef. They estimated that the average WTP for cherry-red ground beef was $2.00/lb more than brownish-red ground beef. Feuz et al. (2020a) investigated consumer WTP for discolored beef by varying levels of discoloration. They observed that the average consumer would require substantial discounts for both beef steak and ground beef, with the level of discount often exceeding the market value of the product. The majority of consumers were found to have strong preferences against discolored beef. However, a minority of consumers were reported to have far less discriminating preferences toward discolored beef, with some consumers even demonstrating a preference for brown color. Discounted discolored beef is not targeted toward the average consumer but rather the minority of consumers who have less discriminating preferences toward discolored beef. As long as the percentage of discolored beef marketed does not exceed the demand of this minority of beef consumers, retailers should still expect to successfully market discolored beef at relatively low discounts. Thus, we are not surprised to find that the weighted average discount for discolored beef across the 2 national retail chains and 1 regional retail chain was only $0.64/lb. A discount of this relatively small size seems appropriate considering the literature (Grebitus et al., 2013; Feuz et al., 2020a), and discolored beef discounted by this amount would be expected to be successfully marketed. However, this is only true if the amount of discolored meat is relatively small.

As the data indicate, 1.5% to 3% of beef placed on sale is ultimately discarded rather than sold at a discount, with a weighted average of 2.55%. It is likely that a portion of this discarded beef may have been discarded after a failed attempt to market it at discount prices. However, some portion of this discarded beef may have simply been discarded rather than discounted first. Experimental evidence suggests that the presence of discolored beef does not reduce the perceived value of adjacent non-discolored beef, and there is some evidence that discolored beef actually increases the perceived value of the adjacent beef, through a decoy effect (Feuz et al., 2020b).

Effects of discarded beef due to discoloration on water, energy, and carbon dioxide equivalent

The total amount of beef discarded per year in the US corresponds to 194.7 million kg. This represents wasting 780,000 animals and associated natural resources consumed through the production of those animals (Figure 2; calculations included in Figure 2 footnote). The current research also determined the impact of discarded meat on the wastage of natural resources and the environment. The estimation of the effects of discarded meat on natural resources was based on published data (Asem-Hiablie et al., 2019).

Based on the absolute amount of meat discarded due to discoloration across the entire beef supply chain, the total loss of water amounts to 34,115 million L from discarded meat (Table 3). About 13,800 million MJ of energy was put into producing and distributing the retail meat, and 581,000 tons of CO_2e were emitted (Table 3). The estimated embedded emissions in discarded meat were prominently generated within cow-calf operations, followed by feed production and finishing feedlots (Asem-Hiablie et al., 2019). Reducing meat discoloration by 1% across the 3 retail stores for both steak and ground beef would limit environmental impacts by 23.95 billion L in water, 96.88 billion MJ in energy, and 0.40 million tons of CO_2e emissions (Table 4). Meat discarded in retail stores results in a negative externality that increases resource scarcity and impacts the environment. An externality exists when one (or more) economic actor

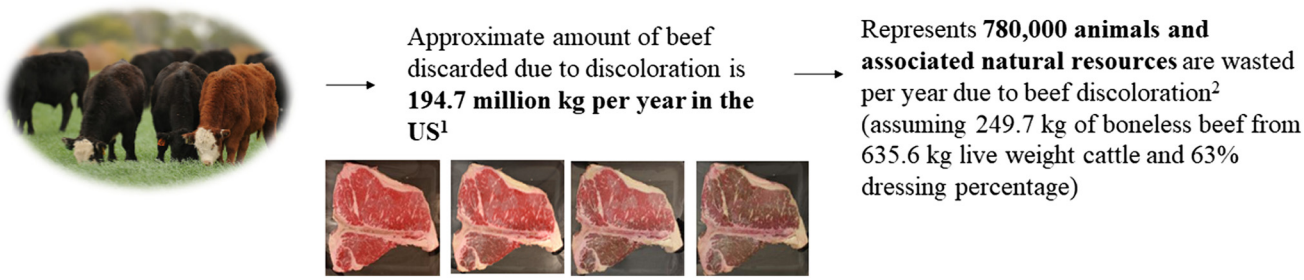

Figure 2. Graphical summary of the number of animals wasted due to discoloration. [1]The average amount of beef discarded due to discoloration represents 2.55%. The total amount of steak and ground beef sold in 2020 was 7.64 billion kg. Therefore the approximate amount of beef discarded was 7.64 billion kg × 2.55% = 194.7 million kg. [2]The number of animals wasted was calculated as 194.7 million kg beef discarded ÷ 249.7 kg = 780,000.

Table 3. Individual store and the national resource consumption and environmental impact from current meat loss

a) Retailer	Resource and environmental impact	Unit	Feed	Cow-calf	Finishing	Packing	Case ready	Total
Retailer A	Energy	Million MJ	71.49	0.84	0.43	0.82	0.60	74.19
	Water	Million L	181.33	0.86	0.81	0.27	0.14	183.40
	CO_2e	Thousand tons	0.54	2.06	0.46	0.04	0.02	3.12
Retail Chain B	Energy	Million MJ	7,780.31	91.35	47.25	89.77	65.36	8,074.04
	Water	Million L	19,734.28	93.71	88.20	29.14	14.96	19,960.28
	CO_2e	Thousand tons	58.43	224.51	50.32	4.33	2.13	339.72
Retail Chain C	Energy	Million MJ	5,446.22	63.94	33.07	62.84	45.75	5651.83
	Water	Million L	13,813.99	65.60	61.74	20.40	10.47	13,972.20
	CO_2e	Thousand tons	40.90	157.16	35.22	3.03	1.49	237.80
b) Estimated to the US based on total discarded beef[1]	Energy	Billion MJ	933.59	10.96	5.67	10.77	7.84	968.84
	Water	Billion L	2,367.99	11.24	10.58	3.50	1.80	2,395.11
	CO_2e	Million tons	7.01	26.94	6.04	0.50	0.26	40.76

[1]Based on Figure 2 data for total beef discarded in the US.

CO_2e = carbon dioxide equivalent.

Table 4. Reduction of water and energy consumption, and CO_2 emission, from 1% decrease in meat discoloration

Retailer	Water saved (million L)	Energy saved (million MJ)	Reduced CO_2e (thousand tons)
Retailer A	1.83	0.74	0.03
Retail Chain B	199.60	80.74	3.40
Retail Chain C	139.72	56.52	2.38
Estimated to the US based on total discarded beef[1]	23.95 billion L	96.88 billion MJ	0.40 million tons

[1]Based on Figure 2 data for total beef discarded in the US.

CO_2e = carbon dioxide equivalent.

(s) affect(s) another actor (or group) directly without a market transaction. Discarded discolored meat generates 2 direct impacts. The first is on the business itself and is denoted by loss of sales revenue. The second is on the general public (or society) in the form of natural resources consumed and environmental costs to produce the feed and livestock and to process, transport, and distribute the products. The first impact is not an externality because retail stores obtain the meat through a market transaction with a price agreement between retailers and upstream producers. The second impact is an externality because natural resources and greenhouse emissions embedded in the production of discarded meat generate no benefit to society. The cost to society includes loss of value of water and energy spent in production and increased production of greenhouse gas emissions. Retail stores do not compensate the public for the societal cost because there is no market transaction between retailers and general public groups. However, the public ends up bearing the burden of these costs, especially the environmental consequences.

The beef industry has adopted several practices to minimize discoloration, such as controlling the postmortem age of fresh beef, packaging, and maintaining cold chain. Cattle feeds have been supplemented previously with vitamin E to enhance immunity and growth rate. The antioxidant effect of vitamin E has also been shown to extend bright-red color. During 4-d display at 3 different stores, cuts (strip loin, T-bone, tenderloin, top-round, top-sirloin steaks, and chuck roasts) from Holstein steers with no vitamin E had discoloration losses of 5.6%, whereas cuts from animals fed vitamin E had 2.0% losses (Williams et al., 1992). Since vitamin E–supplemented feeding had a 3.6% advantage in color stability, Liu et al. (1995) calculated that feeding vitamin E would result in a financial gain of $792 million (based on $22 billion annual retail receipts in the US). When adjusted for US inflation using the consumer price index, this value would equate to $1.36 billion in 2020. The US beef industry is not vertically integrated; therefore, the benefits of vitamin E supplementation would not likely be

implemented unless retailers are willing to pay livestock feeders the cost of feeding a value-added feeding regimen that improves color stability (Liu et al., 1995).

Conclusions

The data collected from 5,034 stores located in 44 states indicated that 13.4 million kg of beef is discarded due to discoloration in the US (on an average 2.55% of total fresh beef sold). Estimating this loss to the annual retail beef sales in the US, the beef industry loses $3.73 billion annually due to discoloration. In addition, 194.7 million kg of nutritious beef is discarded due to discoloration, which corresponds to 780,000 cattle wasted. This study aimed to raise awareness and provide quantitative examples to demonstrate how reducing meat loss due to discoloration in retail stores can maximize natural resource utilization.

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