CONSIDERATIONS FOR THE CONTROLLED FERMENTATION AND STORAGE OF SAUERKRAUT[a]

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INTRODUCTION

The U. S. sauerkraut industry has not maintained its relative competitiveness among food industries, as evidenced by the trend toward reduced per capita consumption of sauerkraut from 2.3 pounds in 1930 to 1.0 pound in 1982 (USDA). Although many factors may contribute to this trend, I wish to discuss in my presentation today the technological factors that we are considering in our research which may increase the demand for sauerkraut.

Improvement in overall quality as perceived by the consumer should be a continuing objective for manufacturers of all food products, including sauerkraut. Perhaps of equal or greater importance for the sauerkraut industry is the need for improvement in uniformity of product quality. Uniformity in quality can influence retail sales of sauerkraut, and may be demanded by more sophisticated institutional buyers. I must say that uniformity in quality is not a strong virtue in U. S. sauerkraut, based on my observations in industry self-evaluation tests at NKPA meetings that I have attended. Industry leaders are aware of this lack of uniformity in quality and are encouraging research for improvement in this regard. Finally, there is a need for new products to adapt to changing tastes of consumers. The new and successful market for wine coolers might serve as an example as to how new products can broaden an industry's market base.

Acidity is an important flavor component of sauerkraut and is highly variable since acids are major end-products from the sauerkraut fermentation. The level of acidity is dependent upon the concentration of fermentable sugars in the fresh cabbage and the extent to which these sugars are converted to acids. Fermentation will continue until all fermentable sugars are depleted or until the product becomes so acidic that lactic acid bacteria are inhibited. It has been suggested that a sauerkraut with a mild acidity might create greater demand by a segment of the population (Burson-Marstellar, 1983). Possible methods for controlling the level of acidity have been discussed (Fleming and McFeeters, 1985) and are briefly summarized in Table 1.

Many European manufacturers control acidity by pasteurization of the sauerkraut when it reaches the desired level of acidity (no. 1, Table 1), which may occur within only 1 to 2 weeks after tanking of the raw cabbage. Herein lies a dilemma for the U. S. sauerkraut industry, which uses bulk tanks for

Table 1. Possible methods to control the level of acidity in sauerkraut[a].

1. Pasteurize when the desired acidity is attained due to fermentation.
2. Develop cabbage varieties to contain only sufficient sugars to result in the desired acidity upon fermentation.
3. Dilute fully fermented kraut to the desired acidity.
4. Partially neutralize fermentation acids by chemical means.
5. Manipulate fermentation by selected microorganisms to produce less acidic or neutral end-products.

[a]From Fleming and McFeeters (1985).

fermentation as well as storage of the product, as previously noted (Fleming and McFeeters, 1985). Although bulk storage is relatively inexpensive and serves to distribute labor and equipment needs throughout the year, it is a major reason for variation in product acidity and the balance of fermentation end-products which include lactic and acetic acids.

Our research is directed toward development of a fermentation procedure that will dictate the final level of acidity attained, without compromising the current advantages of bulk storage. Also, we wish for the procedure to retain quality attributes of the fermented product to the maximum extent. In developing our research approach, it became obvious that a specially designed laboratory fermentor for sauerkraut was needed in order to better control the physical, chemical and microbiological factors that influence the sauerkraut fermentation.

This paper summarizes our recent efforts to characterize the fermentation using a fermentor that we designed for that purpose. Details on design of the fermentor and analytical procedures are published elsewhere (Fleming et al., 1987), but some of the data obtained using the fermentors are given below.

Changes During Fermentation

The sauerkraut fermentation is highly dynamic, with numerous physical, chemical and microbiological changes that may influence quality of the final product. The results to be summarized below suggest that the fermentation may be divided into two stages, the first one gaseous and the second nongaseous. I will attempt to relate the changes that we observed with changes that occur in commercial fermentations.

Physical. The fermentors depicted in Figure 1 were useful in visual observation of some of the physical changes that occur in the sauerkraut fermentation. Volume of the

Figure 1. Experimental fermentors for sauerkraut fermentation. See Fleming et al. (1987) for details.

sauerkraut bed was restricted, which allowed the liquid generated by osmotic release from the cabbage to rise above the bed. A measuring ruler attached to the side of the

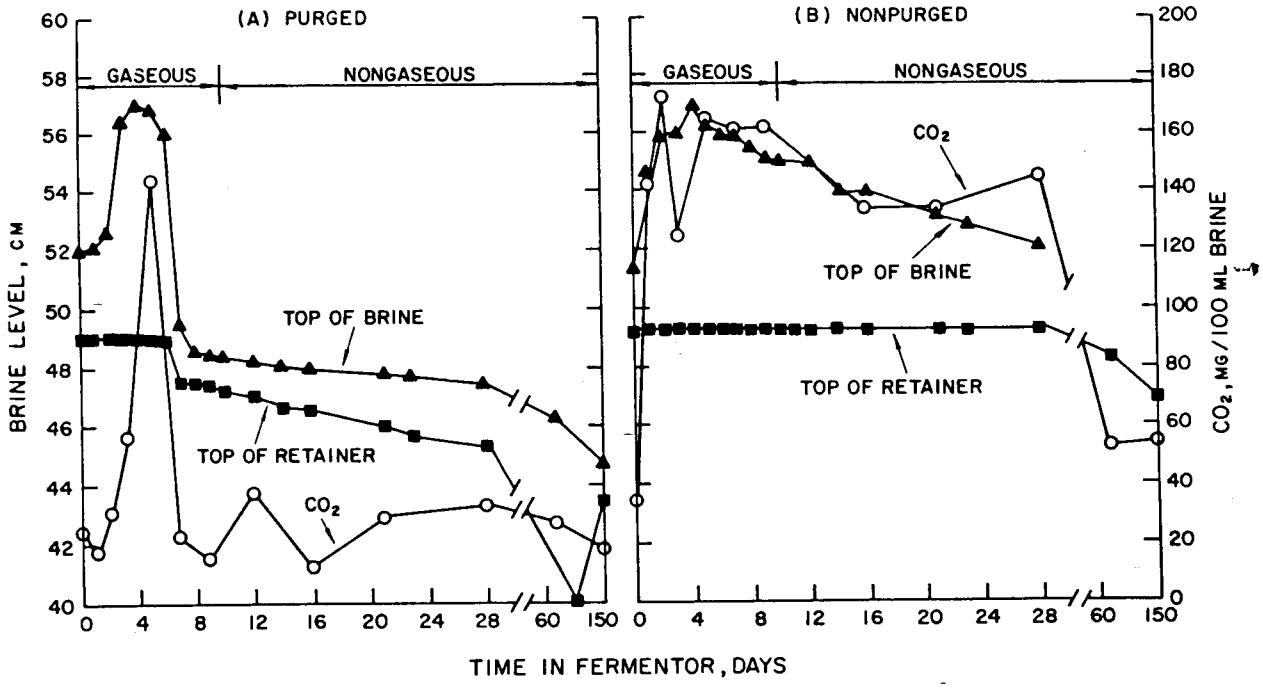

Figure 2. Changes in liquid and kraut bed levels and CO_2 concentration during fermentation. From Fleming et al. (1987).

fermentors was used to determine changes in liquid level. One fermentor was equipped with a side tube for circulation of the liquid (bottom to top) of the fermentor by nitrogen injection. The nitrogen gas served to purge CO_2 from the brine as well as circulate the liquid by gas-lift action.

Changes in brine level and dissolved CO_2 concentration in the purged and nonpurged fermentors are given in Figure 2. The CO_2 concentration peaked at about the same time the brine level peaked. The rise in brine level in the fermentors is analogous to the heaving problem noted in the first few days after filling of commercial tanks. Gas entrapment within the sauerkraut bed forced liquid from the bed and caused the brine level rise. Purging of CO_2 from the brine reduced but did not eliminate rise in brine level (Fig. 2). It is doubtful that CO_2 can be removed from commercial tanks by purging to prevent the heaving problem with present tanking procedures. The cabbage is so tightly packed that brine circulation may be too restricted for sufficient rate of CO_2 removal by nitrogen purging. Alternative methods for ensuring circulation of the brine are being considered. Noel et al. (1979) and Christ et al. (1981) described a system for brine circulation and pointed out the advantages of circulation. They stated that the system allows more control of the fermentation, improves product homogeneity and accelerates acidification by the usual lactic acid bacteria.

Chemical. Chemical changes that result in the production of sauerkraut from cabbage are largely dependent upon composition of the cabbage. The fermentable sugar composition in cabbage used in these studies is given in Table 2. Glucose and fructose were present in largest concentration

Table 2. Fermentable substrate composition of raw cabbage used in fermentations.

Compound	Concentration			
	Leaves		Core	
	mM	%	mM	%
Sucrose	7.0	0.25	53.1	1.91
Glucose	132.5	2.38	75.7	1.36
Fructose	114.2	2.05	60.3	1.08
Total sugars		4.68		4.35
Malic acid	12.2	0.16	7.1	0.09

[a]Averages of 4 replicates. Percentages are by weight, mM = millimolar. Adapted from Fleming et al. (1987).

in the leaves, but sucrose also was present in small amounts. In the core, however, sucrose was highest in concentration based on percent by weight. Since the core represented only 23% of the cabbage weight, overall sucrose concentration was relatively low (0.44%).

When the salted cabbage was placed in the tank, fermentation soon began with resultant acid production and a lowering of pH (Fig. 3). Rate of acid production during the fermentation was relatively rapid during the gaseous stage, slowed at about 8 days, and then increased again.

The depletion of sugars during fermentation is shown in Figure 4. Sucrose was low in concentration, reflecting the relatively low content in the fresh cabbage. Glucose concentration increased in the brine during the gaseous stage and decreased thereafter, while fructose concentration decreased rapidly during the gaseous stage (Fig. 4). Products formed during the fermentation are shown in Figure 5. Mannitol, acetic acid and ethanol concentrations were produced rapidly during the gaseous stage and did not change appreciably thereafter.

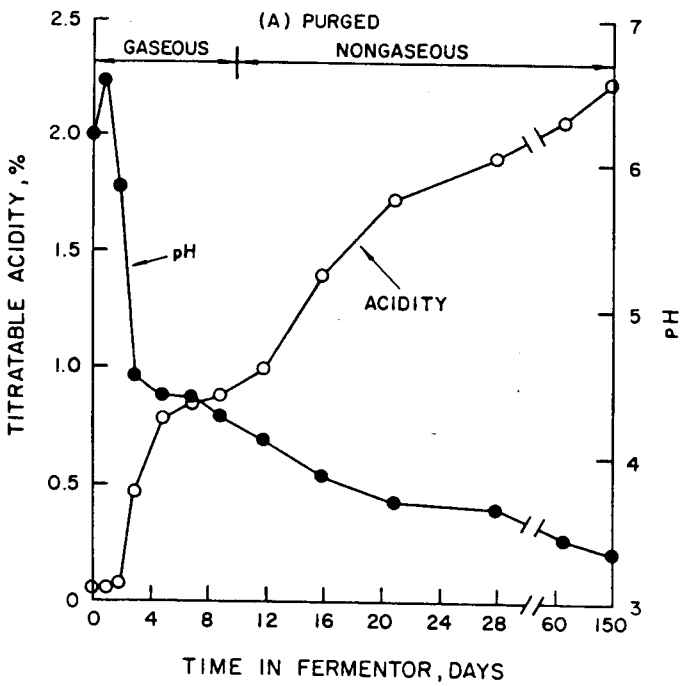

Figure 3. Titratable acidity and pH changes during sauerkraut fermentation. From Fleming et al. (1987).

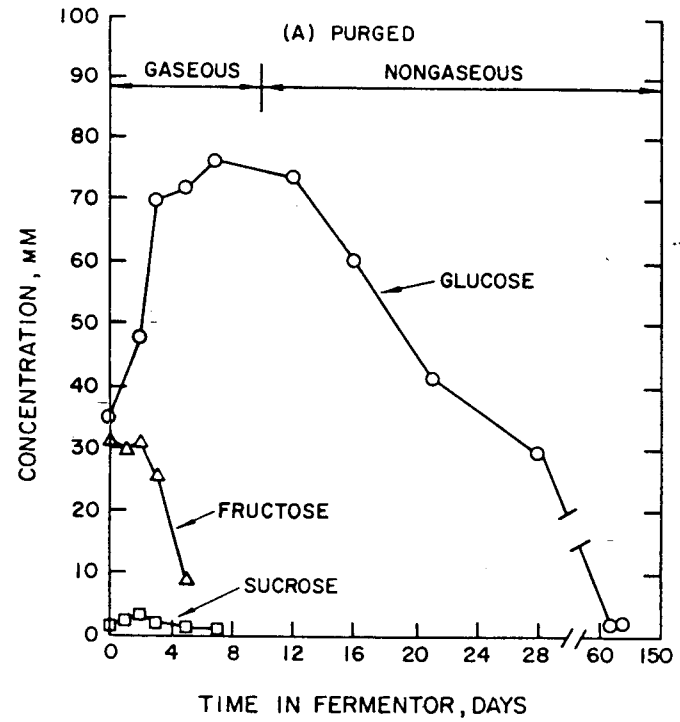

Figure 4. Substrate depletion during sauerkraut fermentation. From Fleming et al. (1987).

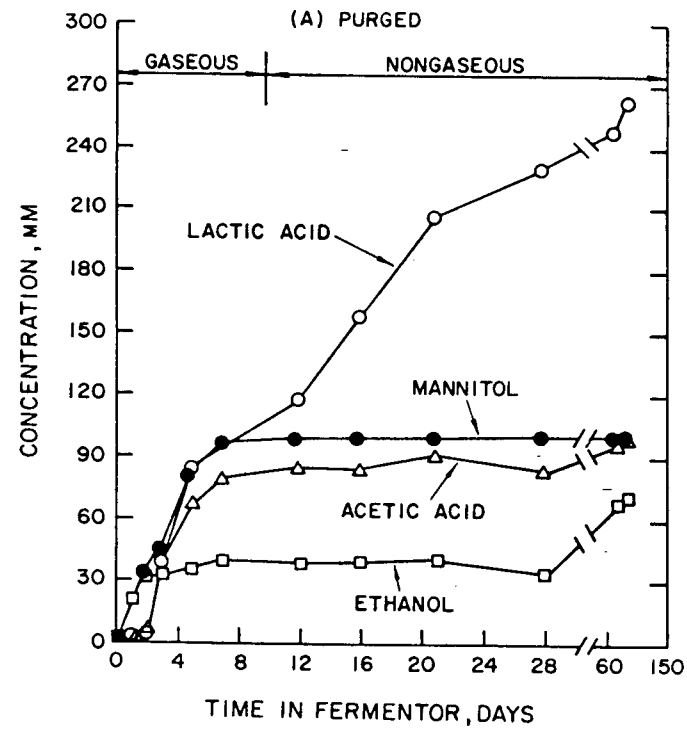

Figure 5. Product formation during sauerkraut fermentation. From Fleming et al. (1987).

Microbiological. Various types of microorganisms are present on raw cabbage, including a relatively small number of lactic acid bacteria. In our case, we found 1.3×10^5 total aerobes, 3.9×10^3 Enterobacteriaceae and only 4.2×10^1 lactic acid bacteria per g of cabbage. Although greatly outnumbered initially, the lactic acid bacteria predominated within about 4 days after the shredded cabbage was slated (Fig. 6). The numbers of

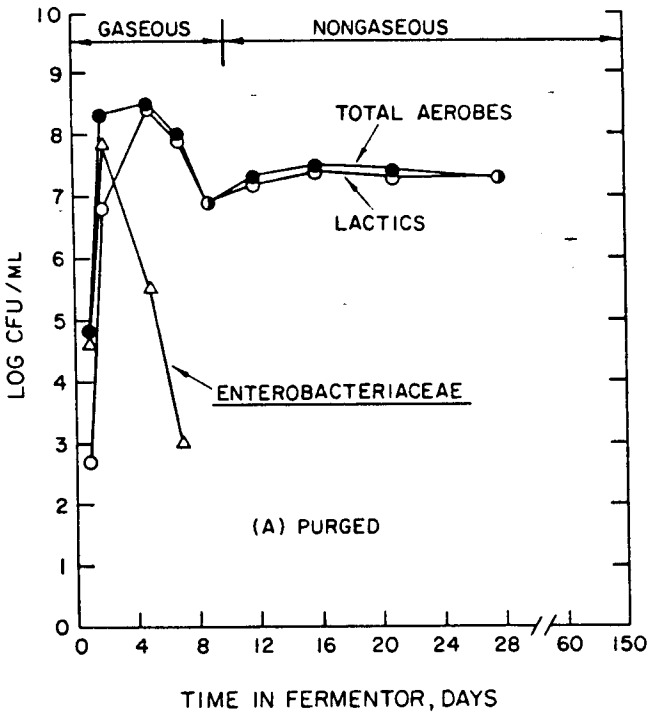

Figure 6. Microbiological changes during sauerkraut fermentation. From Fleming et al. (1987).

lactic acid bacteria peaked at about 5 days and then declined until after 8 days when the numbers increased slightly. Up to about 8 days, most of the lactic acid bacteria were of the gas-forming (heterofermentative) type, typical of Leuconostoc mesenteroides. Beyond 8 days, most of the lactic acid bacteria were of the nongas-forming (homofermentative) type, typical of Lactobacillus plantarum.

These microbiological changes are consistent with the observation of Pederson and Albury (1969) and others for sauerkraut that contains about 2% salt and is held at about 65 F. Pederson and Albury (1969) and Stamer (1983) have indicated that cabbage will ferment spontaneously under the above salt and temperature conditions. They concluded that inoculation for sauerkraut fermentation is unnecessary since the raw cabbage contains sufficient numbers of desirable lactic acid bacteria. This conclusion is essentially the same as reached earlier by Pederson (1930).

We have begun to reconsider the desirability of inoculation, in view of current trends in biotechnology. It may be possible to develop cultures with improved features for use in sauerkraut fermentation. It may be possible, for example, to obtain a heterofermentative bacterium capable of converting more sugars to acetic acid and neutral end-products. This could reduce the amount of lactic acid formed and, thus, reduced the acid harshness in fully fermented sauerkraut. Such a culture might achieve our goals by various mechanisms. Increased tolerance to acidity and production of a bacteriocin against homofermentative lactic acid bacteria are two examples of features that we are considering for incorporation into a selected culture of L. mesenteroides. Bacteriocins are compounds made by certain bacteria, including lactic acid bacteria which inhibit growth of other bacteria. Daeschel and Klaenhammer (1985) described a plasmid (extrachromosomal DNA element) in a strain of Pediococcus cerevisiae that encodes both the genetic information needed for a bacterial cell to produce a bacteriocin and for the producing cell itself to be insensitive (immune) to the bacteriocin. Techniques are rapidly being developed for transferring plasmids among bacteria. Incorporation of the above plasmid into a strain of L. mesenteroides of our choice could result in a new culture with the ability to inhibit growth of homofermentative lactic acid bateria.

Changes During Storage

Physical, chemical and microbiological factors during storage also influence sauerkraut quality, although changes during storage are more subtle than those during fermentation. An excellent product after fermentation can easily deteriorate to an

unacceptable product if storage conditions are not properly controlled.

Physical. Physical changes occur during storage of sauerkraut, although none so obvious as in the heaving stage during fermentation. Multi-layered plastic sheeting on top of the sauerkraut, weighted down by water, provides an excellent seal during the storage period. One could easily become complacent and assume that properly headed tanks are secured and require no attention until needed for processing. Such an assumption could prove costly. Shifting of the sauerkraut occurs due to compaction as gas gradually is dislodged from the product. Tank leakage and temperature changes can also cause movement of the tank contents. These changes may not be important unless they cause dislodgement of the plastic sheeting, which could allow entry of water from the weighting blanket to dilute the product. Dilution of salt and acid could result in spoilage. Also, dislodgement of the sheeting could cause entry of air, which can lead to various chemical and microbiological spoilage problems as discussed below.

Chemical. After fermentation is completed, no major chemical changes occur provided that the fermentation resulted in preservative levels of acid and air is excluded from the sauerkraut. Entry of air through small openings in or around the heading plastic can cause oxidative deterioration of product quality. The problem may be magnified if the brine level is below the level of the sauerkraut. This is true because oxygen diffusion is much more rapid in gas than in liquid. Oxidative reactions can result in darkening and disflavoring of sauerkraut. Ascorbic acid present in the product can act as an antioxidant to delay these changes, but is depleted rapidly in the presence of oxygen.

The sensitivity of ascorbic acid to oxidation is illustrated in Table 3. Sauerkraut juice held in a beaker and exposed to air at room temperature was devoid of ascorbic acid after 6 days. When held under ultraviolet light (254 nm), the ascorbic acid was completely destroyed within 1 day. When held under a nitrogen blanket in the absence of ultraviolet light, however, the ascorbic acid level was reduced only slightly after 6 days.

Table 3. Ascorbic acid retention in sauerkraut juice held under various conditions[a].

Days held	Ascorbic acid, mg/100 ml			
	Frozen	Air	Air + UV	Nitrogen
0	43.6	43.6	43.6	43.6
1		33.8	00.0	43.6
3		26.4	00.0	44.4
6	39.5	00.0	00.0	38.5

[a]Kraut juice held in 50 ml beakers at room temperature.

The use of nitrogen to blanket sauerkraut juice for temporary storage until needed for final product packaging is currently under study by our laboratory in cooperation with the National Kraut Packers Association, Inc. This project evolved from an original inquiry by Mr. King Pharr, plant manger of Shiocton Kraut Company, Shiocton, Wisconsin, after he visited the vegetable fermentation pilot plant sponsored by Pickle Packers International, Inc. (located at Mount Olive Pickle Company, Inc., Mount Olive, North Carolina). He observed our technology of storing fermented cucumbers in closed tanks with a nitrogen blanketed headspace, as described by Fleming et al. (1983).

Microbiological. In the absence of oxygen, fully fermented sauerkraut seems to be microbiologically stable. The level of acidity and the low pH prevent growth of spoilage microogranisms. If air is allowed to contract the sauerkraut, however, a series of microbiological events may occur which can result in product spoilage. In extreme spoilage, even public health concerns exist. Film yeasts typically are the first observable microorganisms to indicate air contamination of sauerkraut. They are frequently found on the surface of sauerkraut in tanks that have been contaminated by air. A cream-colored film and a yeasty odor are symptomatic. The yeasts oxidize lactic and acetic acids, which results in a rise in pH. Molds also may grow and result in softening of the sauerkraut due to

pectinolytic enzymes that they produce. Ultimately, spoilage bacteria may grow and cause serious flavor and other quality problems.

CONCLUSIONS

Sauerkraut is a simple product to manufacture. The sauerkraut fermentation is complex, however, and the manufacture of sauerkraut of uniformly high quality and with the desired level of acidity is not simple. The problem of product uniformity is further complicated when the product is held in bulk storage, since acid formation may continue until the product becomes harshly acidic. Although product uniformity may be improved by canning and pasteurization of the sauerkraut when the desired level of acidity is reached, the economy of bulk storage is lost. Further research is needed to develop methods for the controlled fermentation and storage of sauerkraut. Preferably, such methods will provide sauerkraut of uniformly high quality and will not compromise the benefits of bulk storage.

ACKNOWLEDGEMENT

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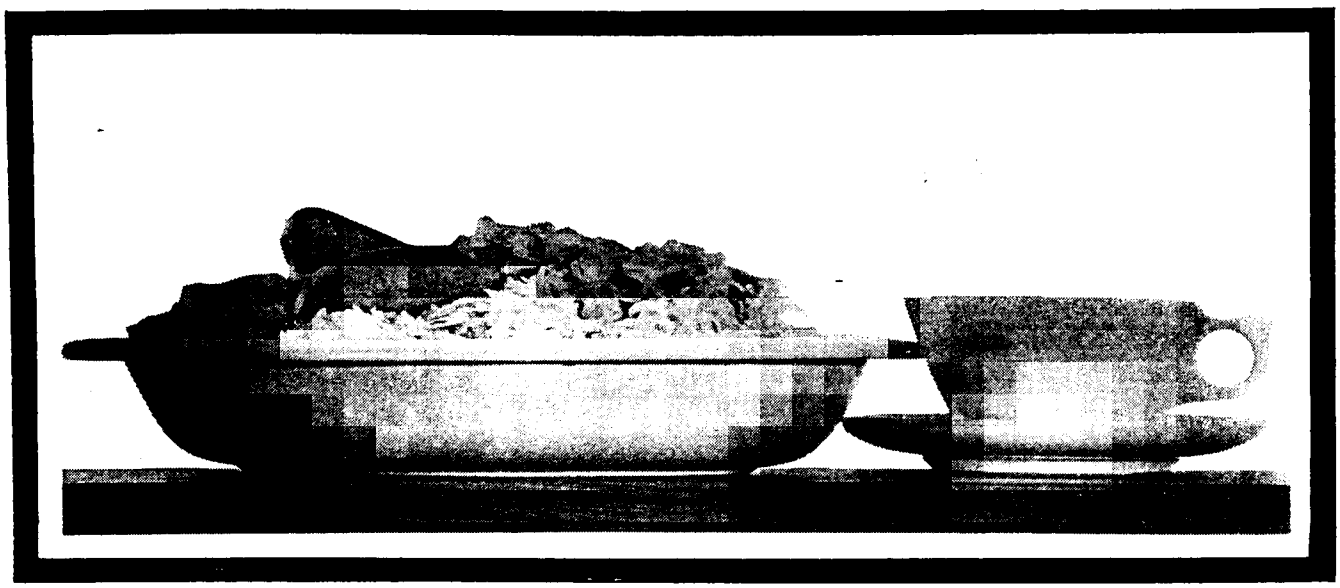

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