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D.B. LUND
EDITOR

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EDITORIAL

I annually take this opportunity to thank all of those associated with the *Journal of Food Processing and Preservation*. Authors, reviewers (see list below), publisher (especially Ms. Kathy O'Neil), and my secretary Mary Wojciechowski all contribute importantly to ensuring the quality and vitality of the *Journal of Food Processing and Preservation*. I want to thank Frank Busta, Owen Fennema, Ted Labuza, and Ken Swartzel who are all completing a three-year term on the editorial board. However, once you have a good team in place, you do not arbitrarily rearrange it. Therefore all four have been reappointed to a three-year term ending in 1993.

The only continuing disappointment with the Journal is the fact we have not had papers submitted in our sections entitled "Computer Codes and Their Applications" and "Databank". We continue to support these two sections and I would invite papers for each section.

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DARYL LUND
Editor

CONTENTS

THE DEVELOPMENT AND TESTING OF A VACUUM ASSISTED JUICE EXTRACTION PROCESS[1]

D. B. CUMMING[2] and R. R. GAYTON

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Accepted for Publication May 11, 1990

ABSTRACT

The application of vacuum during pressing of apple mashes is reported. Apple mash was pressed in a batch system designed to allow application of vacuum to the outlet side of a press screen. Preliminary results indicated significant improvement in throughput rates (up to 100%) when moderate vacuum was applied. Modest yield improvements were also achieved. When the concept was transferred to a commercially available pilot scale screw press, similar results were achieved. Over a wide range of fruit qualities, storage history and varieties (4) production throughput was improved by more than 50% on average using vacuum in the range of 40–70 kPa. Yield improved by 2% ($P < 0.01$) and without affecting suspended solids in the juice. Improvements in production efficiency would have considerable economic impact over a processing season.

INTRODUCTION

The most common means of producing juice (Cumming 1985) from apples and other fruits is based on physical compression of the fruit mash. A variety of systems exist for pressing fruit (Cumming 1984; 1985 and Possmann 1984). The industry standard of performance for yield and quality is still the rack and cloth press. However, this type of press is generally labor intensive and relatively slow. Even the most modern versions of rack and cloth presses suffer these drawbacks to some extent. Continuous presses of various designs have been developed to overcome the efficiency problems of the rack and cloth (Binnig and Possmann 1984; Colesan 1989; Moselang and Bastgen 1988 and Swientek 1985). The design philosophy is for a fast, efficient press that produces high quality juice at yields comparable to the rack and cloth press. One of the most popular types of continuous presses is the screw press (Cumming 1985). There

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are a number of manufacturers of these machines but all are based on a screw of reducing pitch housed in a tapered cone which is perforated to allow escape of juice and having at the end of the cone/screw a tapered, adjustable backpressure plug. The extraction section is generally mounted in a protective housing.

The screw press meets many of the requirements of the processor for efficiency, yield and quality. However, the degree to which a press accomplishes these goals depends on a variety of factors. Only when operating with the highest quality fruit can a screw press be expected to perform to full potential. Yield is one of the parameters that suffers first when conditions are not ideal. To offset the effect of soft fruit, processors use enzyme treatments and/or press aids such as cellulose and other fibres (Glunk 1981; Junker 1987 and Kasper *et al.* 1986). This generally improves yield but tends to reduce throughput. In some instances a lower production rate can help.

Although the original concept leading to this work was centered around improving yield, other parameters such as rate of production and juice quality were also considered important. Finally, it was not intended that the concept be the basis of a new press but rather that it be generally applicable as a modification to most pressing systems.

METHODS

Preliminary experiments were performed with a fabricated bench scale chamber (Fig. 1) which could press a batch of up to 500 g, with or without the application of vacuum. Apples were milled in a hammermill and a weighed amount placed in the chamber. A piston fitted with an O-ring was then used to apply pressure on the mash. When vacuum assist was desired, the bottom section of the chamber could be attached to a controlled vacuum source. A hydraulic jack was employed to apply pressure to the fruit mash. A standard pressing routine was established in which pressure on the fruit mesh was increased to 1986 kPa over one minute and then maintained for up to four minutes. At five minutes the pressure was released and the juice yield measured. Three vacuum conditions were employed, ~ 100 kPa, 50 kPa and 6.5 kPa, representing no vacuum (atmospheric pressure) through fairly high vacuum.

After the preliminary experiments, a commercial pilot screw press (Vetter-Model 1/2) was modified to allow a vacuum to be applied and controlled at the pressing zone. Juice could be removed continuously from the extraction chamber. Pressings were performed on Red Delicious, Golden Delicious, Spartan and McIntosh apples that had a range of storage histories. Normally, an experimental run involved four boxes of fruit or about 72 kg. The press was brought to operating conditions before the measured run was initiated. To prevent feed rate effects, a head of mash (30 cm above the screw shaft) was maintained in the feed hopper.

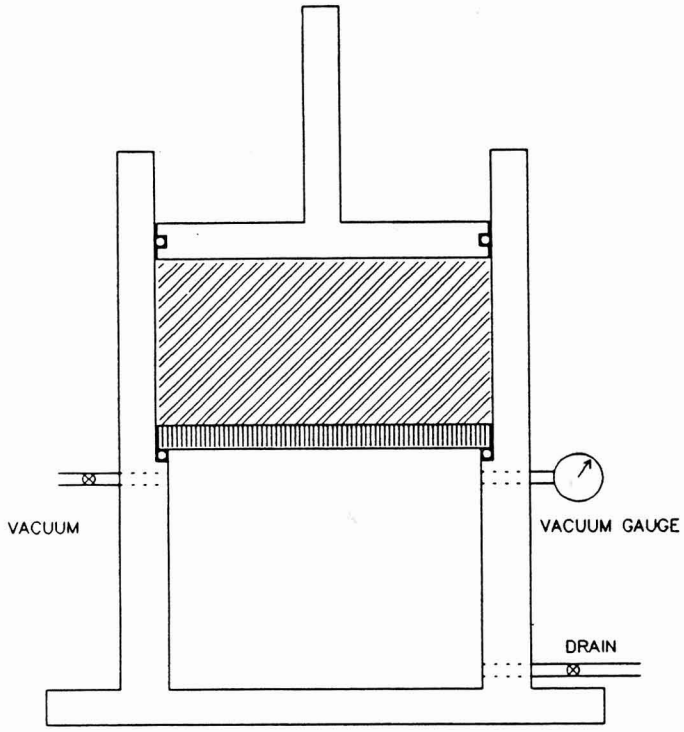

FIG. 1. SCHEMATIC DIAGRAM OF BENCH-SCALE VACUUM ASSISTED PRESS

Yield was measured on a weight/weight basis. Feed rate and pomace production rate were measured as kg/min. Juice soluble solids were monitored by refractometer at 20°C and pomace dry matter was determined by vacuum drying (A.O.A.C. 1984). Suspended solids were estimated as settled solids on a weight basis (100 g juice centrifuged at 3000 × G for 10 min, pellet separated and weighed) and recorded as per cent.

Data were subjected to analysis of variance for a randomized block design using the SAS statistical package. Certain data relating to throughput and suspended solids were subjected to curve fitting routines (best fit). A t-test was performed on paired control and optimized vacuum data for feed rate, juice yield and suspended solids.

RESULTS AND DISCUSSION

Yield is an important component of efficiency. Preliminary experiments indicated that large increases in yield would not be achievable as a result of applying

vacuum. Even though a range of vacuums were employed, yield increases were somewhat marginal in a practical context even though the results (reported later) were found to be statistically significant. Figure 2 represents the effect of vacuum application on press yield. Only the moderate level of vacuum produced a real increase in maximum yield over the 100 kPa control, 64% vs 61%. While such an increase over a production season would be economically significant, the more interesting result was the effective doubling in throughput or rate of production. Figure 2 indicates that the maximum yield of 61% for the 100 kPa treatment was reached in 5 min while that same yield was attained in less than 2.5 min at 50 kPa. These combined results gave encouragement to test the concept at pilot scale.

Using the commercially available Vetter pilot scale screw press provided control yields more in line with expected production yields (75–83% w/w).

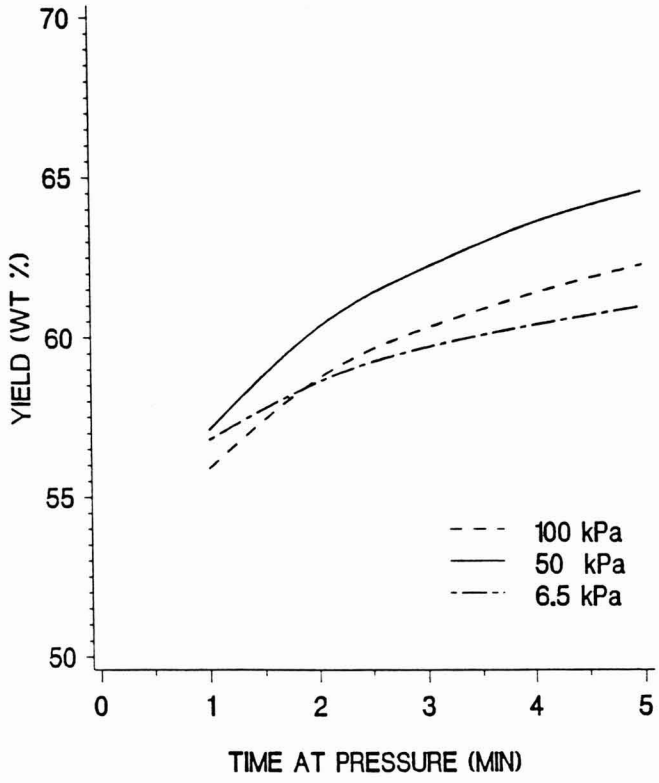

FIG. 2. THE EFFECT OF VACUUM APPLICATION ON JUICE YIELD FOR APPLES PRESSED WITH THE BENCH-SCALE VACUUM ASSISTED PRESS

Results reported here for the pilot experiments represent fruit of varying storage history and pressure test. This accounts for the scatter in the data of Fig. 3 and 4 but also provides a continuum and a practical picture relative to seasonal performance.

As with the bench scale experiments, yield was found to be improved with the application of vacuum. Statistically, vacuum had a positive effect on yield ($P < 0.01$) but most of the increase would be offset by a coincident increase in suspended solids when vacuum exceeded a moderate level. However, suspended solids, at approximately 4% for conditions between 60 and 100 kPa, were higher than normally commercially acceptable (1.5–2%). As vacuum increased beyond 60 kPa, suspended solids increased rapidly to more than 5.5% at 35 kPa (Fig. 3). Since yield and suspended solids seemed to increase in tandem and because suspended solids was not calculated on a weight/weight basis and variability in juice recovery was a function of relatively short runs, it was necessary to consider another measure of extraction efficiency to indicate the real influence of vacuum. Total solids in the pomace seemed to be a likely indicator of true juice removal. Pomace solids would be expected to increase if juice extraction truly increased.

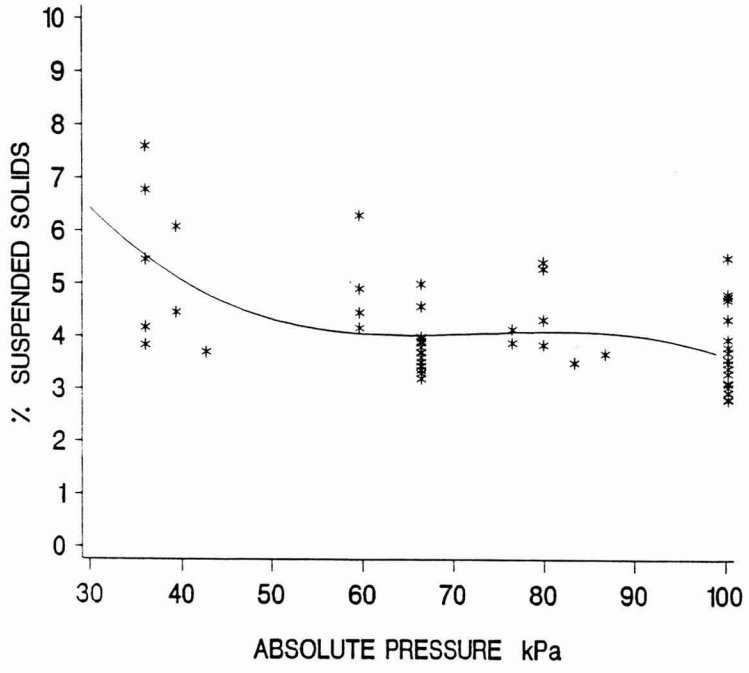

FIG. 3. THE INFLUENCE OF VACUUM APPLICATION ON APPLE JUICE SUSPENDED SOLIDS IN THE MODIFIED SCREW PRESS

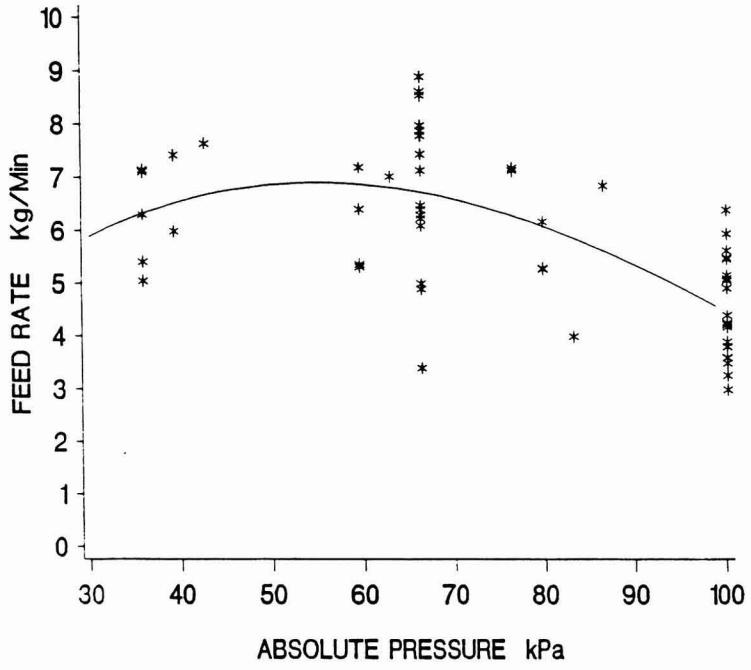

FIG. 4. THE EFFECT OF VACUUM APPLICATION ON THROUGHPUT OF APPLE MASH IN THE MODIFIED SCREW PRESS

When the pooled data were subjected to analysis of variance, a small (approximately 2%) but significant ($P < 0.01$) increase in percent total solids in the pomace was observed with increasing vacuum.

While vacuum increased juice extraction (yield), the greatest effect was seen in rate of production. As with the bench scale experiments, the pilot extraction rates were markedly increased by application of vacuum. Figure 4 indicates that low to moderate vacuum produced the greatest effect. For the varieties employed, there was actually a broad optimum range between about 40 and 70 kPa, with the greatest effect seen at about 55 kPa. When no vacuum was applied, feed rate was averaged at 4.5 kg/min according to the best fit curve while the maximum average feed rate achieved with vacuum assist was 6.9 kg/min. This represents an average increase of 2.5 kg/min or 150 kg/h, an averaged increase of 53% for four varieties and a range of storage conditions. The broad spectrum of experimental conditions approximates production conditions and gives assurance that the results are not just an experimental curiosity, possible only under carefully controlled conditions.

Analysis of variance on the pooled data indicated that there was a varietal effect but all varieties did respond in similar if not equivalent fashion. A paired

comparison for the data from a second, more limited experiment yielded the values in Table 1. McIntosh and Red Delicious apples were used and 67 kPa was arbitrarily chosen as a moderate vacuum to be compared with the control at 100 kPa. These comparisons confirm most of the conclusions drawn previously. A 60% increase in throughput along with a 2% incremental increase in yield and no significant increase in suspended solids ($P < 0.05$) was observed under these conditions.

Kasper *et al.* (1986) and Junker (1987) describe increases in throughput realized by use of press aids and enzyme treatment, respectively. It is anticipated that the vacuum treatment would enhance such improvements even further.

Extensive testing of the concept indicated that application of a moderate vacuum during the pressing of apple mash served to increase yield and throughput rate. Only when the vacuum was increased beyond the moderate level did suspended solids in the juice become an offsetting factor. It is not clear by what mechanism the results reported here are realized. Since juice extraction with a press involves compression of a matrix containing noncompressible fluids, application of vacuum may simply be clearing the juice channels and facilitating the flow of juice out of the matrix. When higher levels of vacuum are applied, two counterproductive factors seem to emerge. Throughput rate begins to drop off, possibly because juice channels are collapsed and screens begin to blind as larger particulates become lodged in them. The other negative factor is the rapid increase in juice suspended solids. Vacuum on the discharge side of the screen likely draws out small particulates which would not necessarily be forced through the press screen by the internal mechanical pressure of the screw.

CONCLUSIONS

Vacuum assisted pressing is both possible and effective. When moderate levels of vacuum (40–70 kPa pressure) are employed, yield is increased an average of

TABLE 1.
COMPARISON OF VACUUM VERSUS ATMOSPHERIC PRESSING OF APPLES

	Pressure		
	Atmospheric 100 kPa	Vacuum 67 kPa	Significance
Feed Rate (kg/min)	4.3 ± 0.93	6.89 ± 1.33	0.001
Juice Yield (% w/w)	96.55 ± 2.15	78.54 ± 1.86	0.007
Suspended Solids (vol %)	3.42 ± 0.62	3.65 ± 0.29	0.098

2% ($P < 0.001$). This increase could be economically significant over a processing season but might not justify the increased cost of the press or a modification procedure. Production rate is increased and could have a highly significant effect in a commercial setting. The practical application of production rate increases is that more finished product can be produced in the same time, fewer shifts can be used to do a season's run and where applicable, the same equipment can be employed to increase production.

While only a screw press was tested at pilot scale, it appears that the vacuum assist concept could be applied to most press designs. In many instances it seems possible to retrofit existing systems as well as to modify press designs at the manufacturing stage. The results of these pilot experiments indicate clearly that a screw press responds very well to the application of moderate vacuum, and preliminary experiments indicated that a platen or rack and cloth type system will also respond well. The application of this concept to specific commercial presses will, of course, require experimentation prior to adoption if the potential of the process is to be fully realized.

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STORAGE AND HANDLING OF BLACK BEANS

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ABSTRACT

Black beans with 10% moisture content were stored for one year in different packaging materials under simulated tropical conditions of 30 ± 3°C, 70–80% RH. Due to improved moisture control, beans stored in impermeable packages (polypropylene/polyethylene and aluminum foil laminate) hardened at a lower rate than beans kept in conventional woven polypropylene bags. Beans stored underground in impermeable packages hardened even less due to lower temperatures. Modified atmospheres of CO_2 and N_2 did not have a major effect on hardness of roasted and untreated beans. Optimal moisture content for storage is 10–14% which is adequate for delaying hardening and minimizing mechanical damage during the handling of beans.

INTRODUCTION

Legumes are important sources of protein in many countries of the Third World. Legumes are often stored as dry seeds for periods of over a year to assure daily availability. In Guatemala, where black beans are consumed daily at 50–60 g per person, imported beans are stored in large silos or warehouses. Beans are eaten as whole seeds after soaking and cooking to a soft texture, a property that is progressively lost during storage at high temperatures and humidities (Aguilera and Stanley 1985). Hardening of legumes is largely unreported but ubiquitous; losses of beans in Central America due to the hard-to-cook (HTC) condition are estimated to be 15–16 million U.S. dollars per year. A consumer survey in Nigeria revealed that HTC is the major problem encountered during storage as noted by 41% of the households surveyed (Phillips 1988).

Reduction of temperature and moisture has been advocated as the simplest way to control hardening of beans (Uebersax 1985). In fact, beans stored at low

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moisture contents (e.g., 5 to 7%) do not harden appreciably at temperatures as high as 37°C (Plhak *et al.* 1982). Beans kept at 35% RH and 15°C for approximately one year showed no significant hardening although many indicators of biochemical changes such as the amount of extractable phenols and *in vitro* peroxidase activity varied during storage (Plhak *et al.* 1987). The strong dependence of hardness on moisture content (or water activity) has been interpreted as a diffusional control of the hardening process (Aguilera and Ballivian 1987). Nevertheless, achieving low moisture content may be expensive, difficult to attain technically and result in seed coat cracking. This last effect apparently sets a practical lower limit for the moisture content of stored beans, although no quantitative data are available for black beans.

Many plant foods, most notably some fruits, benefit from the use of modified atmospheres during storage, although few data are available for legume seeds. Gonzalez (1982) claimed improved cooking quality of beans stored under a carbon dioxide atmosphere and suggested that HTC might be an oxidative process, but these findings were probably influenced by poor moisture control. Mitsuda and Yamamoto (1980) have reported on beneficial effects of grain storage in CO_2 or N_2 atmospheres that suppress respiration, inhibit enzymes and check microbial growth.

Since Chile is a large exporter of black beans to many tropical Latin American countries and has the high temperatures and low relative humidities during summer that are necessary for adequate drying, the objectives of this research were to: (1) analyze hardening of dry beans stored in different packaging materials and stored under simulated tropical conditions; (2) evaluate the effect of gases (N_2 and CO_2) on the hardening rate, and; (3) quantify the effect of reduced moisture contents on the physical integrity of beans during handling and storage.

MATERIALS AND METHODS

Storage in Simulated Tropical Conditions

Black beans (*Phaseolus vulgaris* cv orfeo) harvested in March, 1988, and sundried to about 10% moisture were stored (20 kg) for about 340–380 days in bags of: woven polypropylene fibers (WPP), the currently used packaging material; WPP with an internal 150 μm thick low-density polyethylene bag (WPP/PE), and WPP with a Kraft paper bag inside. Additionally, beans were stored in cellulose fiber drums (25 L) with metal lids or in laminated polyester-aluminum foil-polyethylene (PET/Al/PE) bags that are the best flexible water vapor barrier available in Chile. For identification, samples stored in different packages are referred to as "beans" preceded by the type of packaging material.

Two wooden enclosures (2 × 2 × 2 m) were constructed. The first was insulated with 2.5 cm thick polystyrene foam panels covered with polyethylene

film on all interior surfaces. A temperature-relative humidity device automatically maintained conditions inside this room at 30 ± 2°C and 70–80% RH, simulating conditions in tropical countries. In the ground below this floorless room was dug a cavity (50 × 50 × 70 cm deep) that was lined with wood on the sides and overlapping but unsealed polyethylene film on all surfaces. This underground storage was covered with a flush, tight-fitting 15 cm thick polystyrene foam lid. Into both storages were placed the five samples described above (the fiber drum was not used in the underground storage). The second wooden enclosure was placed adjacent to the first but automatic controls were not used and conditions were allowed to fluctuate throughout the storage (10–25°C/40–80% RH). Hardness and moisture content of beans as well as the temperature and relative humidity of the chambers were determined regularly. Bean soaking and cooking was as described in Aguilera and Ballivian (1987). Hardness of beans was expressed relative to the initial hardness at storage time 0 or F/F_0. Moisture content (wet basis) was calculated as the g of water (by oven drying) divided by the weight of the original sample × 100.

Storage in Modified Atmospheres

Black beans were roasted at 80°C for 2 min according to the procedure described by Aguilera *et al.* (1987) to inactivate enzymes. Both, roasted and control (unheated) bean samples (100 g) were adjusted to 14% moisture content, placed in small bags of PET/Al foil/PE, filled with air, N_2 or CO_2, tightly sealed and stored in controlled temperature incubators at 31 or 35°C for 11 months. Headspace samples were analyzed monthly to verify tightness of the seals using a Shimadzu GLC 9A gas chromatograph with a Supelco Carbosieve SII column.

Physical Damage

Beans with intact seed coats and similar sizes were conditioned to moisture contents of 6, 11.6, 14.2 and 17.2% by exposure to air above saturated salt solutions. Three tests were designed to simulate handling of black beans during storage and to evaluate physical damage: (1) Free fall—individual beans were dropped inside a metal pipe from a height of 6 m onto a metal plate; (2) abrasion—a 75 g sample of beans was placed inside a horizontal stainless steel cylinder (14 cm dia. × 20 cm length) and rotated around the long axis at 44 rpm for 20 min; (3) static load—a single layer of beans was maintained for 1 week under 65 kg sand bags to give a pressure of 0.3 kg/cm^2, similar to a 4 m column of beans in a silo. After testing, beans were visually examined and classified into six categories: B1, undamaged or intact; B2, broken seed coats adhering to the cotyledon; B3, broken and loose seed coats; B4, dented seed coats; B5, broken seeds or splits, and; B6, crushed seeds.

RESULTS AND DISCUSSION

Figures 1 and 2 present the relative hardness and moisture content of beans stored under simulated tropical conditions, respectively. After one year beans stored at 30°C, 70–80% RH in WPP, a fiber drum or WPP/paper showed a significant ($p < 0.5$) greater relative hardness than beans stored in more impermeable containers such as the WPP/PE or the Al foil laminate. WPP beans were 4.2 times harder at the end of the storage period than at harvest (F/F_0 = 4.2) and almost 3 times harder than WPP/PE beans (F/F_0 = 1.8). A hardness of 4.2 exceeds the maximum acceptable value of 2 after a standard 2 h cook

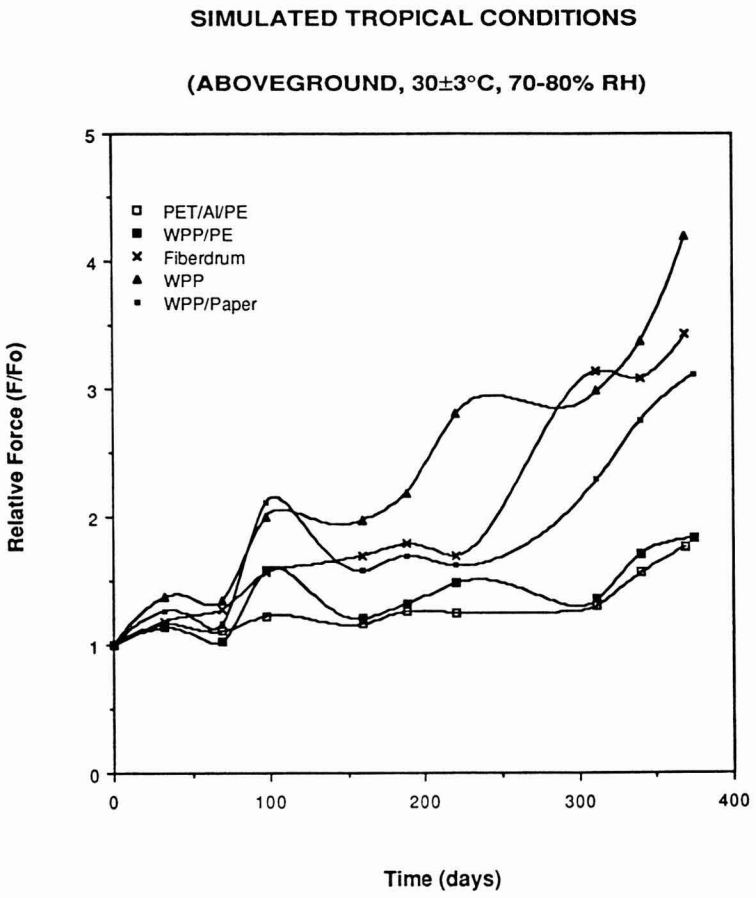

FIG. 1. HARDNESS OF COOKED BLACK BEANS STORED ABOVE GROUND UNDER SIMULATED TROPICAL CONDITIONS (30 ± 3°C, 70–80% RH) EXPRESSED RELATIVE TO TIME ZERO (F/F_0)

Hence, beans stored one year in WPP need extra cooking time to soften to the acceptable level, increasing energy consumption.

Rate of hardening is a strong function of the moisture content of beans and the storage temperature (Aguilera and Hohlberg 1989). Results in Fig. 1 relate directly to the moisture content of beans reported in Fig. 2. While beans in packages of WPP/PE and PET/Al/PE maintained a stable moisture content of approximately 11.5% (range 10.5–12.0%), those in the more permeable packaging materials rapidly reached a significantly ($p \leq 0.5$) higher moisture content. The equilibrium moisture content of beans at 70–80% relative humidity and 30°C is between 14–15%; this compares well with the final moisture content of beans

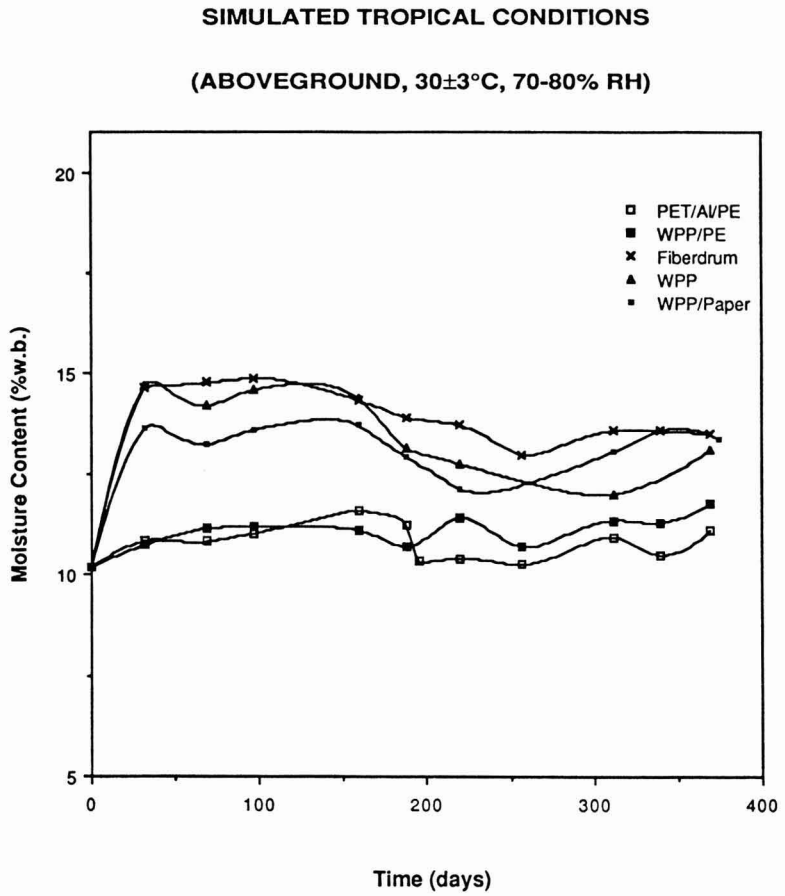

FIG. 2. MOISTURE CONTENT OF BEANS STORED ABOVE GROUND IN SIMULATED TROPICAL CONDITIONS (30 ± 3°C, 70–80% RH)

stored in more permeable materials. The relative moisture equilibration rates of beans are related to the water vapor permeability of the packages, which for WPP and WPP/PE are in a ratio of about 500:1 (Warham 1986).

Underground storage in simulated tropical conditions reduced the incidence of bean hardening. While the average temperature above ground was 30°C, it dropped to 18–22°C underground, an 8–12°C difference in the range where the contribution of temperature is important. WPP beans did not harden appreciably for 150 days (Fig. 3) but the hardening rate increased dramatically as a consequence of moisture uptake, coinciding with the start of the rainy season (Fig. 4). At the end of the storage period the relative hardness of subterrain WPP

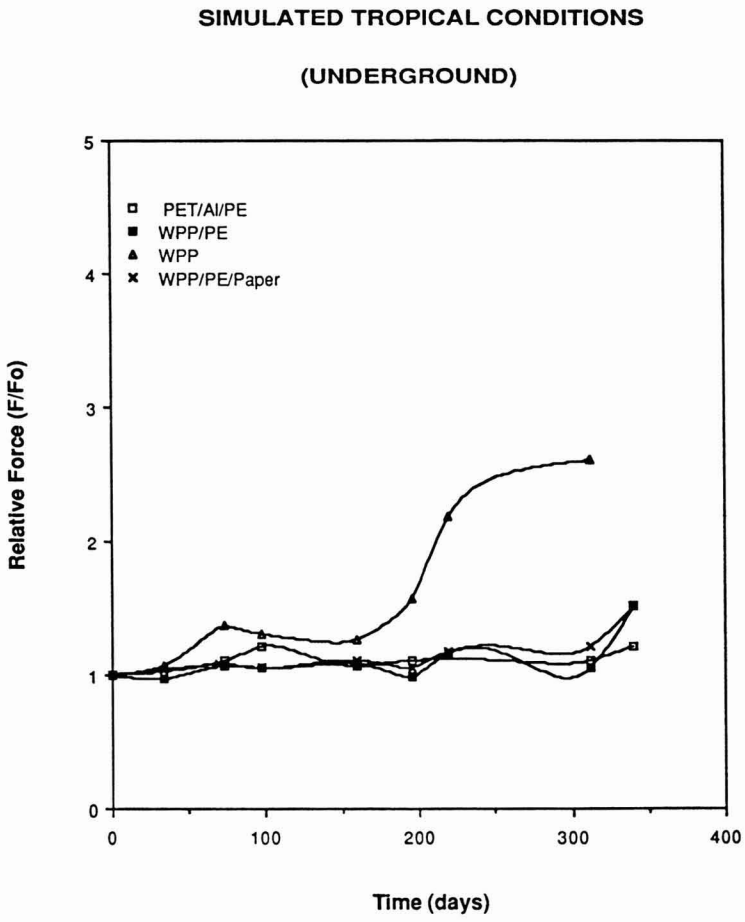

FIG. 3. HARDNESS OF COOKED BLACK BEANS STORED UNDERGROUND IN SIMULATED TROPICAL CONDITIONS EXPRESSED RELATIVE TO TIME ZERO (F/F_0)

beans exceeded 2.5, but this was significantly less than for WPP beans stored above ground. Beans stored underground in WPP/PE bags did not reach a $F/F_0 = 1.5$, showing the combined beneficial effects of a low initial moisture, protective packaging and reduced storage temperature. Moisture contents of WPP, WPP/PE and WPP/PE/Paper beans were higher than in beans kept above ground due to condensation of moisture from the cavity. This translates into a higher driving force for moisture vapor transmission in semipermeable packaging materials, particularly for WPP (Fig. 4). The superior water vapor barrier property of the PE film was demonstrated by the slower moisture pick-up of WPP/PE beans stored underground compared to WPP alone. The net cost of adding the internal PE film to the WPP bag is 25 cents (U.S.) per 50 kg or about 0.5 cents

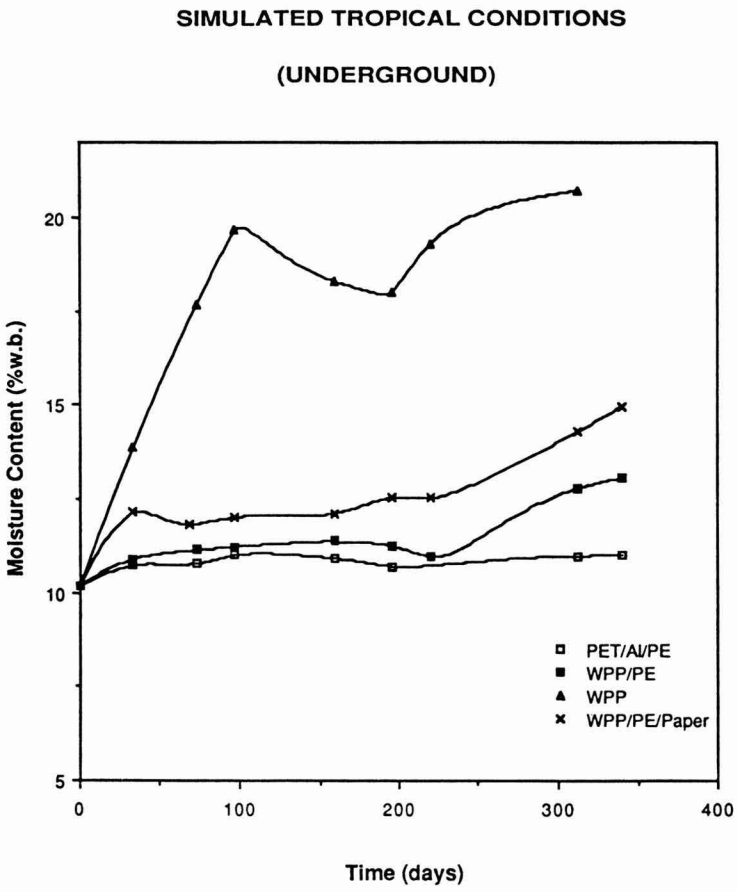

FIG. 4. MOISTURE CONTENT OF BEANS STORED UNDERGROUND IN SIMULATED TROPICAL CONDITIONS

per kg; beans are sold at a retail price exceeding $1 per kg. In this improved package the WPP bag still provides adequate resistance to handling while the PE film is an inexpensive moisture barrier. The even better performance of the foil laminate as a moisture barrier is confirmed in Fig. 2 and 4, but its high price precludes commercial use.

Results for ambient storage conditions are presented in Fig. 5 and 6. Stored beans did not exceed a cooked texture of 1.5 and final moisture contents were below 12%. These results stem from the fact that during winter high relative humidities prevail but temperatures are low while in summer the mean temperature increases but the relative humidities are low (50–60%). No significant

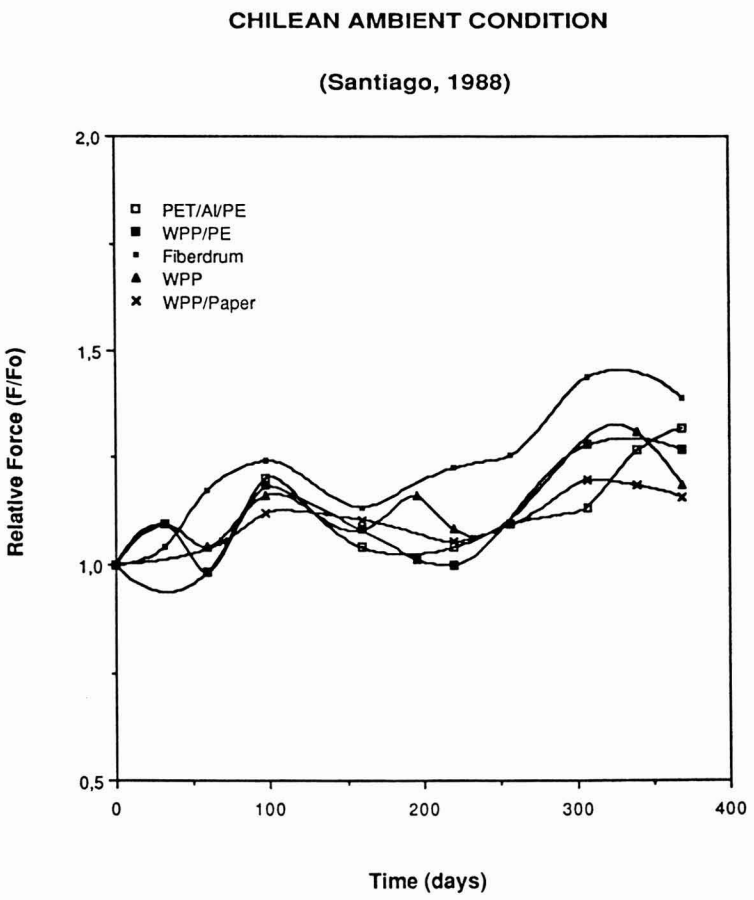

FIG. 5. HARDNESS OF COOKED BLACK BEANS STORED UNDER AMBIENT CONDITIONS EXPRESSED RELATIVE TO TIME ZERO (F/F_0)

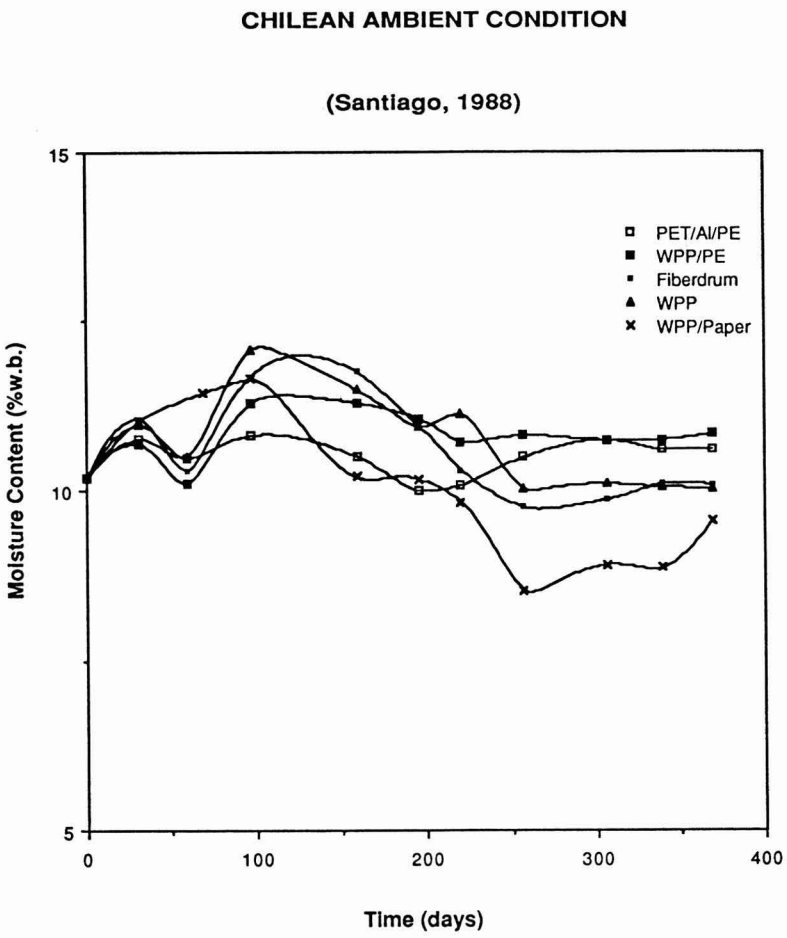

FIG. 6. MOISTURE CONTENT OF BEANS STORED UNDER AMBIENT CONDITIONS

differences ($p \leq 0.05$) were found and the average standard deviation of relative hardness for the range of values reported was around 0.15.

Storage tests under modified gas atmospheres were aimed at detecting whether gross differences in hardening rates existed as previously reported in the literature (Gonzalez 1982). Relative forces for beans stored at 31°C are presented in Fig. 7. Data for 35°C were generally similar but more accelerated and are not shown. The concentration of CO_2 increased during storage for beans kept in atmospheres containing air or nitrogen while it decreased in beans maintained under carbon dioxide. Figure 7 shows that as a group untreated beans at 31°C hardened to a lesser extent than those heat-treated but this result was not as clear at 35°C. This

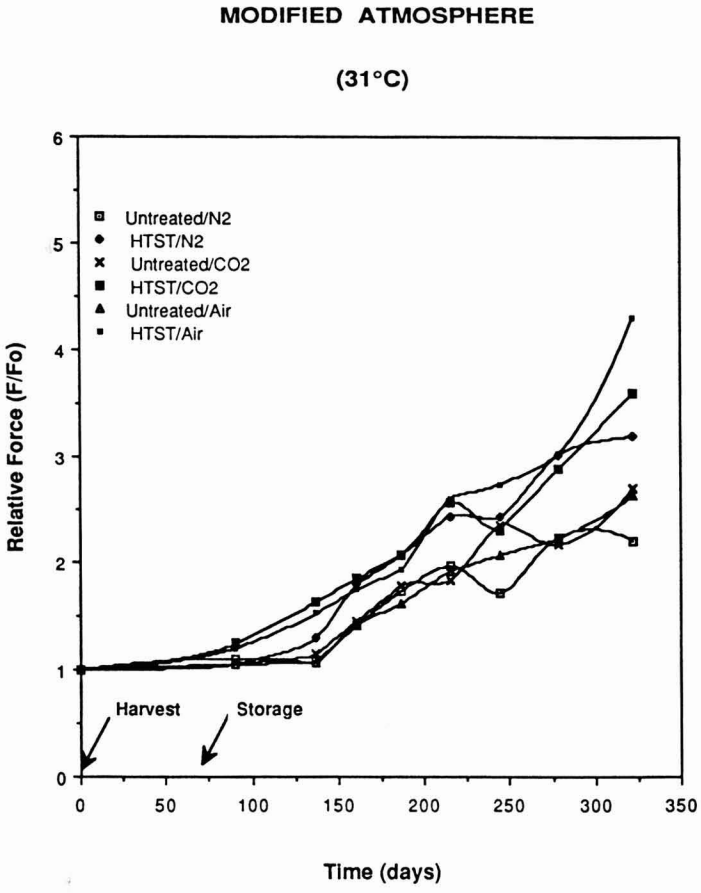

FIG. 7. HARDNESS OF COOKED ROASTED AND UNTREATED BEANS (14% MOISTURE CONTENT) STORED IN AIR, CO_2 OR N_2 AT 31°C

behavior has been explained to result from microstructural damage induced by dry roasting that accelerates hardening and counteracts the role of heat treatment in deactivating enzymes (Aguilera *et al.* 1987). No clear advantage from the standpoint of hardness control is achieved by using modified atmospheres, although roasted beans may benefit from storage under a CO_2 or N_2 atmosphere at lower temperatures. Possible advantages of storage under inert gases, not tested in this study, are the prevention of mold growth and mycotoxin formation (Banks 1981). It is interesting that the use of CO_2 in grain storage is recommended for its inhibitory effects of reactions in the seed that lead to its production (Mitsuda and Yamamoto 1980). No appreciable effect of the use of a CO_2 atmosphere on hardening rate was detected under conditions of this study. Slow biochemical

reactions occuring at reduced moisture contents that require low concentrations of certain reactants (e.g., oxygen) may proceed due to the incomplete removal of air from the internal tissue and slow equilibration. Further biochemical studies to test specifically for the incidence of respiration on hardening rates of beans are required.

Since lowering the moisture content of beans is an effective way to reduce the hardening rate, the effect of this treatment on physical properties important during storage and handling was also studied. As commented upon by Mohsenin (1970), mechanical damage of beans such as separation of the testa constitutes a real problem faced by the bean industry. Damage to the seed coat is related to moisture content during harvest and subsequent handling. Results of the simulation of physical damage occurring during handling and storage of beans are presented in Table 1. For all three tests (free fall, abrasion and static loading) intermediate moisture contents of 11.6 and 14.2% resulted in a higher proportion of intact beans. When all beans with broken seed coats (B2 and B3, Table 1) were considered together the intermediate moisture range was less detrimental,

TABLE 1.
VISUAL INSPECTION OF BEAN DAMAGE PRODUCED BY PHYSICAL TESTS

		Percent in each category						
Test	**W(%)**	**B1**	**B2**	**B3**	**B4**	**B5**	**B6**	**N**
Free Fall	6.0	63.8	3.1	29.0	1.5	2.7	0.0	483
	11.6	77.1	1.6	19.1	1.6	0.5	0.0	682
	14.2	74.9	1.6	21.1	2.1	0.2	0.0	426
	17.4	73.9	6.0	16.4	3.7	0.0	0.0	353
Rotating Screw	6.0	75.2	4.4	19.2	1.2	0.0	0.0	338
	11.6	81.2	2.6	13.6	2.6	0.0	0.0	308
	14.2	84.2	1.6	10.6	3.6	0.0	0.0	310
	17.4	73.9	12.5	3.9	6.1	0.0	0.0	353
Static Loading	6.0	72.0	4.5	16.7	6.6	0.0	0.0	532
	11.6	76.8	7.9	11.1	3.6	0.0	0.7	443
	14.2	86.7	0.7	10.6	0.9	0.0	1.1	445
	17.4	74.1	3.5	15.8	4.0	0.0	1.5	398

W/% water content: B1, undamaged; B2, broken seed coats but adhering to the cotyledon; B3, broken and loose seed coats; B4, dented seed coats; B5, broken seeds or splits, B6, crushed seeds, N, total number of beans visually inspected.

with low moisture contents (6%) being the worst. These results are in agreement with those of Narajan (1969) who reported an optimum moisture content for minimum checking of navy bean seed coats in the range of 13.4 to 15.6%. The data also show that under conditions of this experiment free fall induces bean splitting while static loading mainly causes crushing. These two effects are offset with respect to moisture content since at low moisture levels the cotyledon is hard and the seed coat brittle while at high levels the bean becomes softer and the hull more plastic.

Average moisture contents of beans in the range of 10 to 14% are low enough to slow hardening but higher than those where seed coat damage becomes important. It should be pointed out that artificial drying is sometimes used to reduce moisture contents of wet beans and that drying conditions are critical if seed coat damage is to be prevented. For example, if the relative humidity of the drying air is lower than 30%, cracking of seed coats becomes a major problem in white beans (Otten *et al.* 1984).

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FACTORS AFFECTING EXTRUSION CHARACTERISTICS OF EXPANDED STARCH-BASED PRODUCTS

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ABSTRACT

Effect of feed moisture, oil, protein, sugar, salt, grain size and barrel screw speed on expansion index, torque, pressure, texture, output and final moisture of extruded puffed products were studied. Sugar, salt, and oil improved expansion of the product. Increased feed moisture, protein, sugar, salt and barrel screw speed favorably decreased the torque or pressure in the extruder, and improved the texture of the product. The final moisture in the product was only related to the feed moisture and oil content of the raw material. Reducing grain size increased the expansion, hardness and output of the product and reduced the extruder pressure. All these factors probably influenced the extrusion characteristics of expanded products by affecting the starch-starch interaction. Viscosity studies on the expanded starch indicated that water, protein and sugar decreased the dextrinization of the starch during puffed extrusion, while salt increased the dextrinization.

INTRODUCTION

Extrusion technology is now widely used in the manufacture of a diverse range of food products, including pasta, snacks, breakfast cereals, confectionary, texturized meat substitutes, infant food formulations, precooked beverage powders, and extruded crispbread.

Various researchers have put forth efforts to get a deeper insight into the process, but it is not always clear what variables affect the quality of the extruded product. Feldberg (1969) reported that the amylose/amylopectin ratio of corn starch influenced the textural properties of their extruded products. Mercier and

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Feillet (1975) examined the behavior of different cereal starches (corn, waxy corn, amylomaize, rice,wheat) to extrusion and found that an increase in amylose content is accompanied by a decrease in expansion, but this behavior was reversed in some measure at high extrusion temperature. Bhuiyan and Blanshard (1982a, 1982b) found no clear correlation between extrusion behavior with either protein contents, starch damage, total or free fatty acid content and composition, or the bound water relationships of the starch. However, all satisfactorily extruded maize starches had amylose content above 35%. The favorable extrusion behavior also correlated with lower gelatinization temperature and a more rapid gelatinization process.

Roberts and Guy(1987) tried to relate proposed metastable states to moisture movement within the screw system by observing dependent process variables such as torque, pressures and mass temperatures. Maurice and Stanley (1978) studied the effect of feed moisture, barrel temperature, screw speed, etc. on certain selected textural properties of extruded products from soybean meal, whereas Phillips *et al.* (1984) used cowpea meal for their studies.

There is a need to develop food products of high protein quality, high calorie value, high acceptability and relatively low cost, for children or other nutritionally vulnerable group. Cereal flours or grits with added plant protein, coextruded to give expanded products, may provide one solution (Molina *et al.* 1983). This work attempts to study the composition of formulation and variables that affect the characteristics of extruded expanded starch-based products.

MATERIALS AND METHODS

Corngrits, cornstarch and soya protein were provided by Brabender OHG Duisburg. Glutinous rice was obtained from the retail shops near the University. The moisture content of the samples were determined and the calculated amount of water, oil, salt, sugar or soya protein were added to the samples and thoroughly mixed in an electric food mixer for more than 10 min before the extrusion was performed.

Extrusion

A Brabender laboratory food extruder with a 1.90cm barrel diameter, and a 20:1 barrel length to diameter ratio was used. The screw speed was varied in the range of 120–250 rpm. For determining the effects of various food component, the screw speed and feeding screw speed were kept constant at 175 and 110 rpm, respectively, for experiments using cornstarch, and at 160, 80 rpm, respectively, for experiments using corngrits. A screw compression ratio of 4:1 was used. The temperatures in the extruder were controlled electrically at 150°C (feed zone), 180°C (metering zone), and 180°C (compression zone) to obtain a

puffed product. A 3.00 mm die nozzle diameter were used. The extruder was equilibrated with cornmeal and the hopper at the feeding port was kept full throughout the extrusion run (Bhattacharya *et al.* 1986).

The Expansion ratio/index was defined as (the average diameter of the extruded product)/(the diameter of die nozzle). Each value is the average of 12 to 16 readings.

The hardness (texture) was determined using the Instron Universal testing machine by compressing the samples at a crosshead speed of 5 cm min^{-1}. It is taken as the average yield stress (ie maximum stress before fracture (N)) of triplicate determinations (Mohamed *et al.* 1989).

Amylose content was determined by the reaction with KI/I_2 (Morrison and Laignelet 1983).

The Viscosity changes with time and temperatures of extruded and unextruded starch were measured using a Brabender Viscograph E and the temperature was increased from 40°C to 95°C and back to 35°C at a rate of 3°C/min. The amounts of starch used were calculated so that the viscosity is in the range of 700 cmg (Brabender units). The aqueous suspension of samples were: 11.6% for unextruded corngrits, 8.4% for unextruded cornstarch, 19.3% for extruded corngrits and $13.5 \pm 0.3\%$ for extruded cornstarch after taking into account the sugar, soya protein and moisture content.

RESULT AND DISCUSSION

Effect of Initial Moisture Content on Extrusion Characteristics of Corngrits (Fig. 1a)

Increasing the feed moisture of the raw material from 13–16% decreased the expansion and hardness of the product, and reduced the dependent process variables such as torque, pressure, and output of the product. The higher moisture food tend to be less viscous than the lower moistured food, therefore gave a lower torque and internal pressure. The amount of expansion depended on the pressure difference between the die and the atmosphere which was smaller for higher moistured food. The decrease in expansion was similarly observed by Bhattacharya *et al.* (1986) and Harper (1981). The lower viscosity of the higher moisture food may also be responsible for the increase in output. The addition of moisture also assists gelatinization, swelling and degradation of the starches, which explains the lower force needed to fracture the puffed product (hardness values) from higher moistured materials. Gomez and Aquilera (1983) showed the breakdown of starch polymers during extrusion were greater in the lower moistured raw materials as evidenced by electron micrograph and the lower viscosities of the starch in suspension at various temperatures and time. The

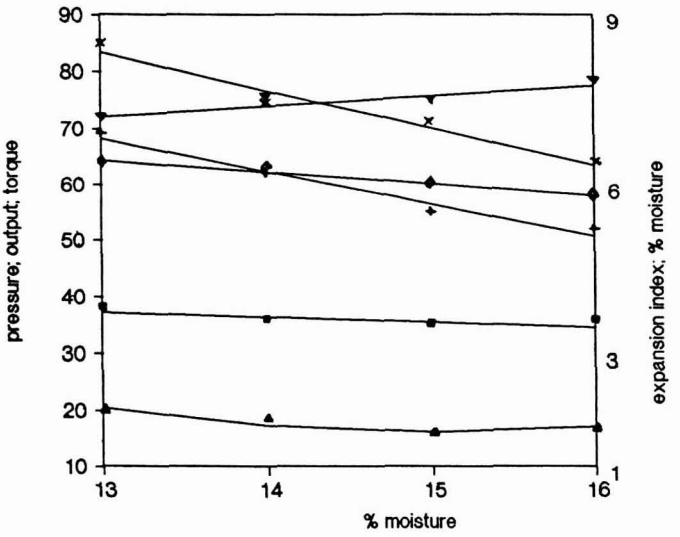

FIG 1A. EFFECT OF INITIAL MOISTURE CONTENT ON DEPENDENT VARIABLES OF EXPANDED CORNGRITS

\+ Torque (Nm)
◇ Pressure (0.5 Nm^{-2})
Δ Texture (N)
x Output (g/min)
■ Expansion index
∇ Final moisture (%)

present study on viscosity of extruded starch show similar results (Fig. 2a) and helped explain the greater puffed volume of low moistured raw materials.

The addition of moisture assisted extrusion by increasing lubrication, heat transfer, extruder capacity and reduce extruder wear or power consumption. The final moisture of the product was affected by the feed moisture.

Effect of Added Corn Oil to Extrusion Characteristics of Corngrits (Fig. 1b)

The oil content of the raw material did not correlate well with the torque, pressure, output or texture of the product. It indicated that oil did not help in lubricating or reducing the viscosity in the barrel. The addition of 4% and above oil to corngrits caused the extruder to jam, under the set extrusion condition. Increasing oil content,however, increased the expansion and decreased the final moisture of the product, probably by increasing the efficiency of heat transfer.

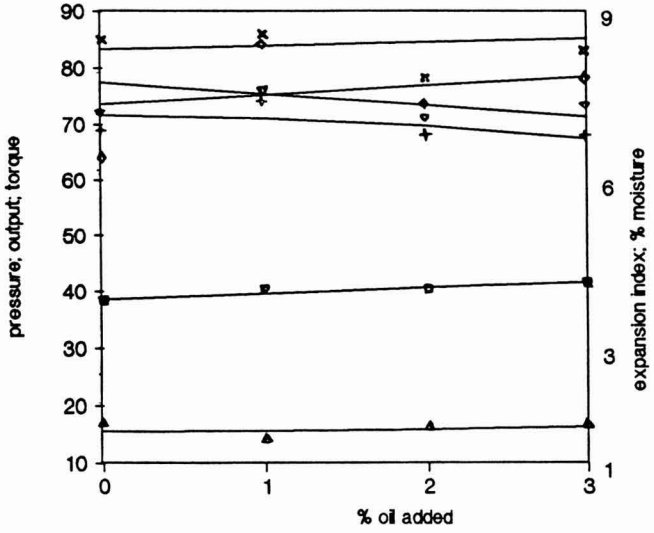

FIG. 1B. EFFECT OF ADDED OIL ON DEPENDENT VARIABLES OF EXPANDED CORNGRITS
(Legends, see Fig. 1a)

Effect of Added Soy Protein to Extrusion Characteristics of Cornstarch (Fig. 1c)

Increasing the soya protein content from 0–25% resulted in decreased expansion, hardness, output, torque and pressure of puffed extruded cornstarch. All the extruded product had the microstructure of expanded cornstarch. The decrease in expansion is as expected since the protein does not puff as well as the starch. Furthermore viscosity studies showed that increasing the soya protein content appeared to reduce the dextrinization of the corn starch as observed by the increased gelling ability on cooling of the cornstarch containing increasing amounts of soya protein (Fig 2b).

The decrease in hardness could be due to the interference of starch-starch interaction by the protein molecules. This protein interference in starch-starch interaction during the plastic state could also be observed by the lower torque and pressure reading in the extruder barrel indicating lower resistance and cohesiveness of the starch. The lower pressure may also explain the lower output obtained with increasing soya protein content in the formulation.

Effect of Added Sugar to Extrusion Characteristics of Cornstarch

Increasing the sugar content from 0–10% caused an increase in expansion, but a decrease in hardness, torque, pressure, and output of the product (Fig.

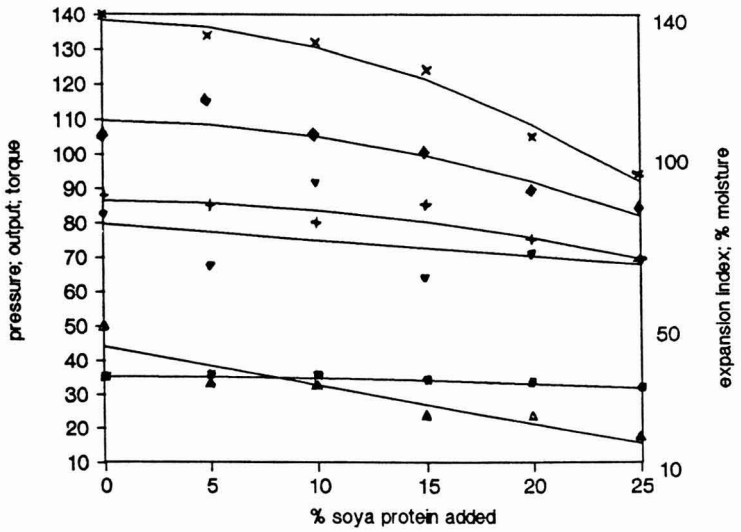

FIG. 1C. EFFECT OF ADDED SOYA PROTEIN ON DEPENDENT VARIABLES OF EXPANDED CORNSTARCH
(Legends, see Fig. 1a)

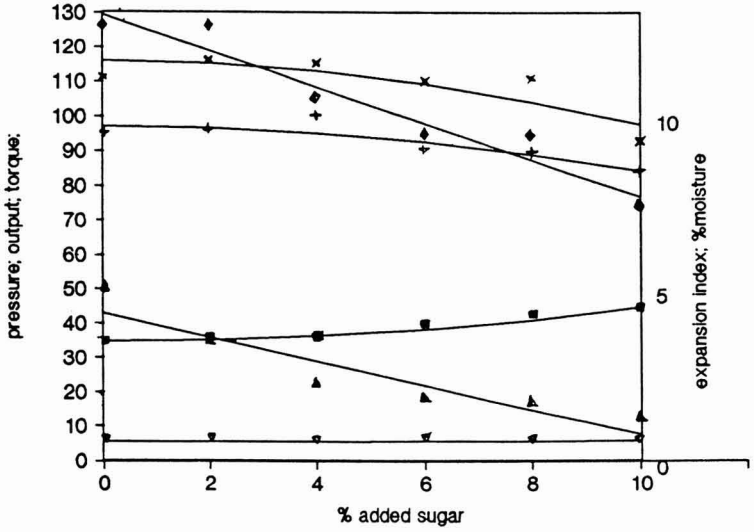

FIG. 1D. EFFECT OF ADDED SUGAR ON DEPENDENT VARIABLES OF EXPANDED CORNSTARCH
(Legends, see Fig. 1a)

1d). The sugar could have melted under high temperature and shear, thus exerting an effect similar to water. Viscosity measurements at various time and temperatures showed that increasing sugar content reduced the dextrinisation of the starch by extrusion (Fig. 2c) similar to the effect of increasing moisture content. Likewise the output is reduced probably because of the reduced pressure in the barrel.

The increase in expansion and decrease in hardness indicated a decreased starch-starch interaction in the presence of increasing sugar content.

Effect of Added Salt to Extrusion Characteristics of Corngrits

Increasing the salt content from 0–2.5% resulted in an increase in expansion and a decrease in hardness of the product and pressure reading (Fig. 1e) showing that salt too interferes with the starch-starch interaction. Moreover viscosity measurements (Fig. 2c) showed that salt increased the polymer breakdown (dextrinization) of the starch molecules. A salt content of more than 2.5% made the product too salty to taste. However, since the % of salt used is small, its effect on torque and output may be insignificant.

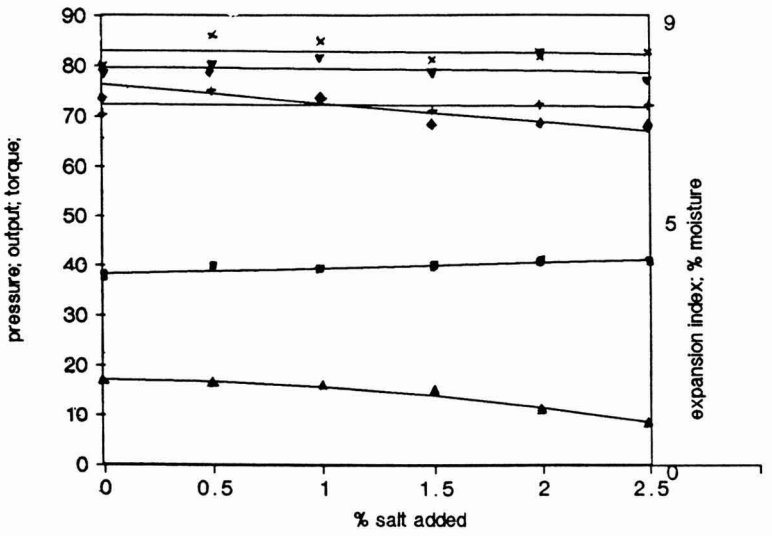

FIG. 1E. EFFECT OF ADDED SALT ON DEPENDENT VARIABLES OF EXPANDED CORNGRITS
(Legends, see Fig. 1a)

Effect of Grain Size to Extrusion Characteristics of Corngrits

Increasing the grain size of the raw material caused an increase in pressure in the barrel and a decrease in expansion, hardness and output of the product (Fig. 1f). The increase in pressure indicated greater resistance in the barrel with larger grain size. Under this circumstance the increase in pressure does not result in increased output nor expansion of the product. Decreasing the grain size may result in greater starch damage and caused increased expansion and hardness of the product. This agreed with the observation of Bhuiyan and Blanshard (1982), that the extent of starch damage was lower in maize grits than in maize flour.

Viscosity measurements of the expanded starch from milled and unmilled rice were identical, showing that the degree of dextrinization during extrusion is not affected by grain size.

Effect of Barrel Screw Speed to Extrusion Characteristics of Corngrits (Fig. 1g)

Increasing the barrel speed decreased the torque, pressure, output and hardness of the product. This is a useful observation since raw materials which are difficult to extrude would require greater barrel screw speed and lower feeding screw speed to reduce the torque and pressure in the barrel. It is a general practice to

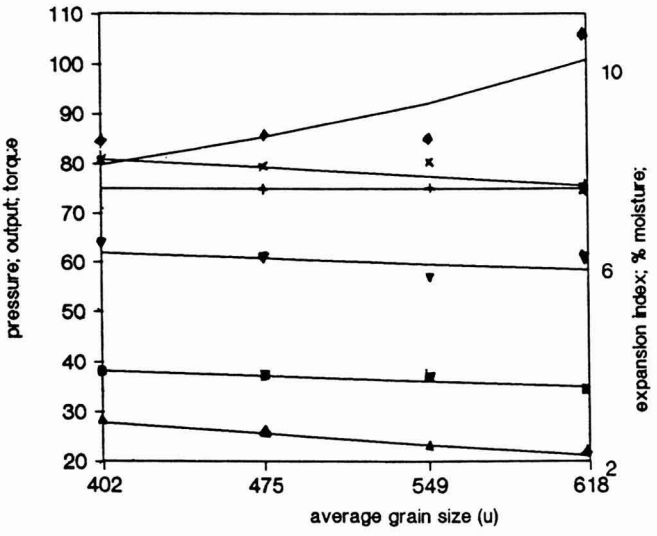

FIG. 1F. EFFECT OF GRAIN SIZE ON DEPENDENT VARIABLES OF EXPANDED CORNGRITS
(Legends, see Fig. 1a)

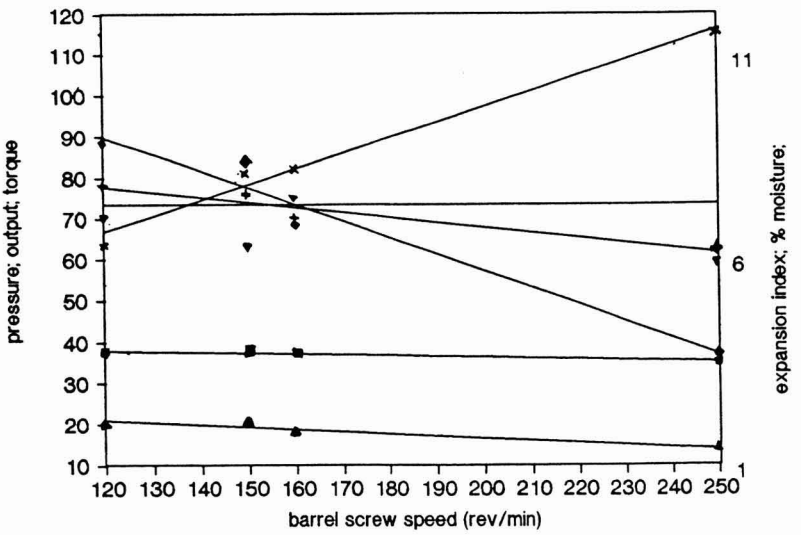

FIG. 1G. EFFECT OF BARREL SCREW SPEED ON DEPENDENT VARIABLES OF EXPANDED CORNGRITS
(Legends, see Fig. 1a)

quickly increase the barrel screw speed when the material is about to get stuck in the extruder (as observed by the sudden increase in pressure). Glutinous rice which had a very low amylose content of 0.02–0.04% were successfully puffed and extruded at a barrel screw speed of 175 rpm and a feeding screw speed of 40 rpm. Table 1 shows the suitable conditions for extrusion of puffed starch based products from glutinous rice, corn grits and corn starch.

CONCLUSION

(1) The expansion ratio of an extruded product is favorably affected by increasing sugar, salt, and oil content and unfavorably affected by increased grain size, moisture, or protein content. The regression analysis for data on expansion ratio are presented in Table 2.

(2) The torque in the extruder barrel is favorably affected by increasing barrel screw speed, moisture, protein, and sugar content in the formulation. The regression analysis for data on torque are presented in Table 3.

(3) The pressure in the barrel is also favorably affected by increased screw speed, feed moisture, protein, sugar and salt content, and decreased grain size. The regression analysis for data on pressure are presented in Table 4.

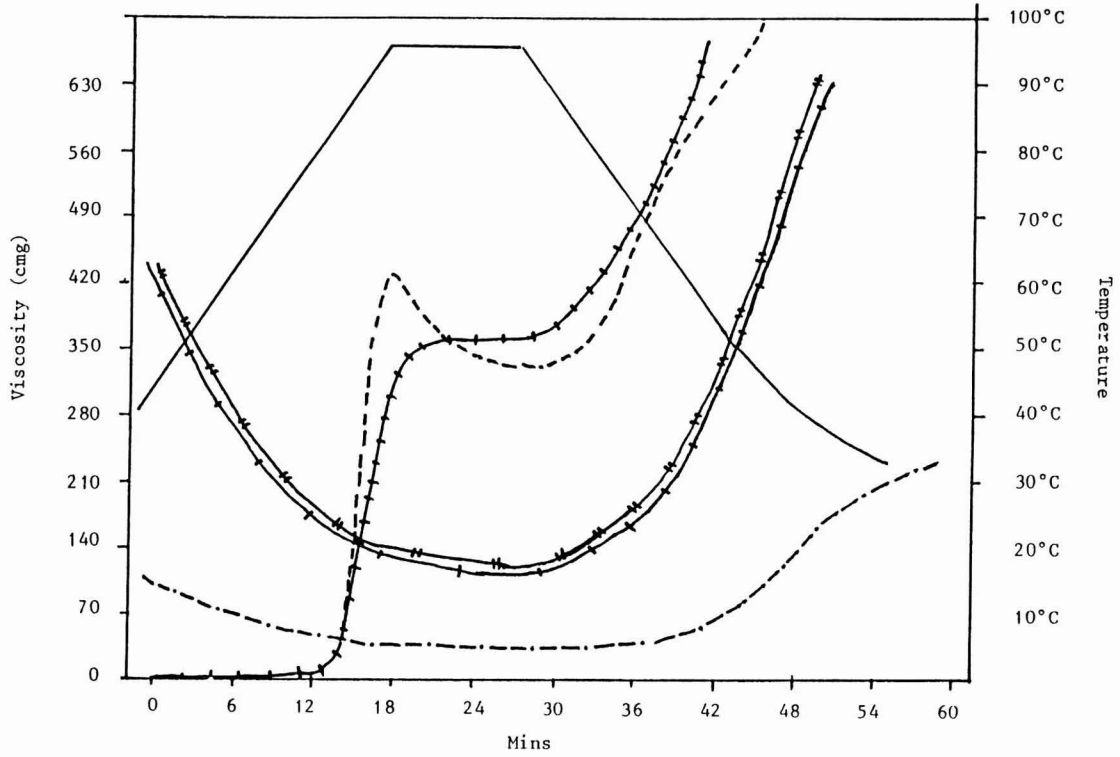

FIG. 2A. EFFECT OF INITIAL MOISTURE CONTENT AND PUFFED EXTRUSION ON THE VISCOSITY OF CORNGRITS AND CORNSTARCH AT VARIOUS TEMPERATURES AND TIME

Viscosities of:

Temperature

Unexpanded corngrits

Expanded corngrits with 13% initial moisture

Expanded corngrits with 16% initial moisture

Expanded corngrits containing 2.5% salt

Unexpanded cornstarch

Expanded cornstarch containing 5% soya protein

Expanded cornstarch containing 10% sugar

Expanded cornstarch

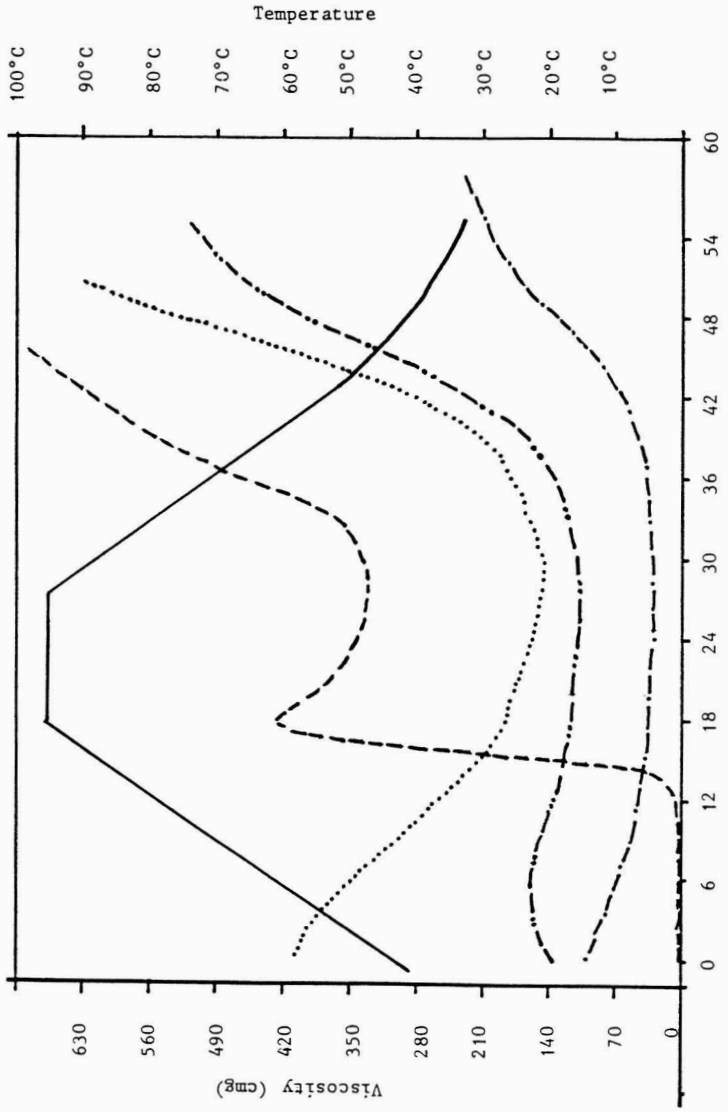

FIG. 2B. EFFECT OF ADDING SOYA PROTEIN TO THE EXTRUSION MIXTURE ON THE VISCOSITY OF PUFFED EXTRUDED CORNSTARCH
(Legends, see Fig. 2a)

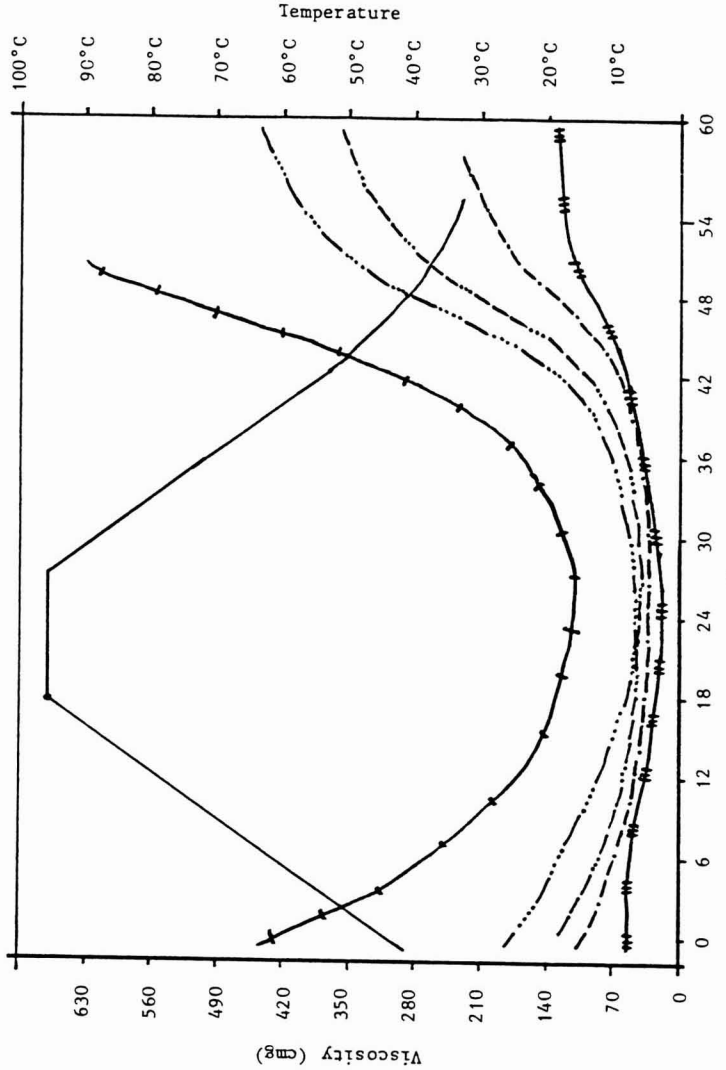

FIG. 2C. EFFECT OF ADDING SUGAR AND SALT TO THE EXTRUSION MIXTURE ON THE VISCOSITY OF PUFFED EXTRUDED CORNSTARCH AND CORNGRITS
(Legends, see Fig. 2a)

TABLE 1.
SUITABLE CONDITIONS FOR EXTRUSION OF EXPANDED STARCH-BASED PRODUCTS

sample		glutinous rice	corn grits	cornstarch
feed screw speed	(rpm)	40	80	110
barrel screw speed	(rpm)	175	160	175
initial moisture	(%)	13.8	13	12.3
torque	Nm	73	75	88
pressure	(kp/cm^2)	63	69	105
temperatures	(°C)	180	180	180
output	(g/min)	117	83	140
expansion index		3.06	3.83	3.48
texture	(N)	32.5	21	50
final moisture	(%)	6.96	7.5	8.21

(4) Texture is favorably affected by increased barrel screw speed, feed moisture, protein, sugar, salt and reduced grain size. The regression analysis for data on texture are presented in Table 5.

(5) The output is increased by increased screw speed, and decreased feed moisture, protein, sugar and grain size. The regression analysis for data on output are presented in Table 6.

(6) The final moisture is only affected by feed moisture and oil content. The final moisture for data on expansion ratio are presented in Table 7.

TABLE 2.
REGRESSION ANALYSIS FOR EXPANSION RATIO IN RELATION TO VARIOUS INDEPENDENT VARIABLES

Independent variables (x)	Best fitted line Expansion ratio (y) =	r^2	Estimated std. error of Y
initial moisture	$4.9 - 0.009x$	0.58	0.12
oil	$3.9 + 0.11x$	0.77	0.10
protein	$3.5 - 0.00053x^2$	0.94	0.05
sugar	$3.5 + 0.01x^2$	0.95	0.10
salt	$3.8 + 0.11x$	0.82	0.06
grain size	$4.1 - 0.0000015x^2$	0.68	0.11
barrel screw speed	$3.9 - 0.0000054x^2$	0.54	0.13

TABLE 3.
REGRESSION ANALYSIS FOR TORQUE IN RELATION TO VARIOUS INDEPENDENT VARIABLES

Independent variables (x)	Best fitted line Torque (y) =	r^2	Estimated std. error of Y
initial moisture	$143.6 - 5.8x$	0.97	1.6
oil	$72 - 0.44x^2$	0.41	2.7
protein	$87 - 0.027x^2$	0.85	3.1
sugar	$97 - 0.13x^2$	0.77	3.0
salt	$72 - 0.094x^2$	0.018	1.9
grain size	75	-	-
barrel screw speed	$92 - 0.12x$	0.92	2.4

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TABLE 4.
REGRESSION ANALYSIS FOR PRESSURE TO VARIOUS INDEPENDENT VARIABLES

Independent variables (x)	Best fitted line Pressure (y) =	r^2	Estimated std. error of Y
initial moisture	$91.7 - 2.1x$	0.97	0.6
oil	$74 + 1.65x$	0.11	6.0
protein	$110 - 0.044x^2$	0.88	4.0
sugar	$130 - 5.25x$	0.93	6.0
salt	$76 - 3.77x$	0.62	3.0
grain size	$66 + 0.000088x^2$	0.64	7.0
barrel screw speed	$138 - 0.405x$	0.96	5.0

TABLE 5.
REGRESSION ANALYSIS FOR TEXTURE IN RELATION TO VARIOUS INDEPENDENT VARIABLES

Independent variables (x)	Best fitted line Texture (y) =	r^2	Estimated std. error of Y
initial moisture	39 - 1.5x	0.83	1.0
oil	16 + 0.1^2	0.07	1.6
protein	44 - 1.1x	0.87	4.6
sugar	43 - 3.5x	0.86	5.9
salt	17.2 - $1.4x^2$	0.98	0.6
grain size	40.2 - 0.031x	0.99	0.3
barrel screw speed	28 - 0.054x	0.88	1.3

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EVALUATION OF FIBER INGREDIENTS PRODUCED BY ENZYMIC AND/OR YEAST FERMENTATION OF TRITICALE

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ABSTRACT

The chemical composition, nutritional properties, and functional characteristics of various fiber ingredients prepared by enzymic and yeast fermentation of triticale were evaluated. Drying and other processing parameters, including the effect of varying the level of residual starch, sugar, or soluble solids on ingredient composition were determined. Triticale fiber ingredients produced by fermentation had similar in vitro *protein digestibility values compared to products made from wheat. Levels of Fe, Ca, and Zn were higher in triticale fiber ingredients than for comparable wheat fiber products, bran, or oat bran, suggesting that the nutrient availability for these minerals may be higher for triticale products. These fiber ingredients from triticale were incorporated at flour replacement levels of up to 15% (w/w) in yeast raised bread, yielding products with acceptable color, appearance and crumb grain scores products. Comparative data for other fiber ingredients are also presented.*

INTRODUCTION

Currently over 1 million hectare (ha) on a worldwise basis are devoted to the production of triticale (x *Triticosecale* Wittmack) a polyploid hybrid developed by cross breeding wheat and rye. Projections are that triticale will eventually be cultivated to the same or greater extent than durum wheat (approx. 8 million ha). A number of undesirable agronomic characteristics in early varieties of the grain such as sterility, low yield potential, lodging, and seed shriveling, which

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have limited the utility of triticale as a source of food, have been overcome for the most part (Skovmand *et al.* 1984).

Triticale has been underutilized as a human food partly due to the relatively poor milling properties and baking characteristics of milled triticale flours, plus the tendency of triticale products to stale more quickly (Lorenz *et al.* 1972; Tsen *et al.* 1973). Modifications to conventional breadmaking procedures such as elimination of bulk fermentation or use of a mechanical development process have been developed to improve the baking performance of triticale flours. In addition, triticale has been evaluated as a major component in cakes, breakfast cereals, chemically leavened foods such as pancakes, pasta products, and as a brewing adjunct (Skovmand *et al.* 1984).

The major use of triticale remains as an animal feed ingredient (Adeola *et al.* 1988) and as a forage crop (MacIntyre and Campbell 1973). Triticale has a higher protein content and a slightly better protein quality than wheat (Kies and Fax 1985). Trypsin and chymotrypsin inhibitors and alkylresorcinolic compounds have been isolated from the grain which may reduce feed quality, however the levels of these antinutritional factors are relatively low and similar to that of wheat and rye.

Relatively little work has been conducted on the use of triticale as a source of starch as a feedstock material for industrial or food fermentations, or on food ingredients manufactured from triticale, other than flour. The objective of this research was to develop and evaluate fiber ingredients produced from whole triticale and to compare these materials with fiber ingredients made by fermenting wheat, milo and barley; rice bran, oat fiber and prune fiber. The performance characteristics of fiber ingredients from apples (Chen *et al.* 1988); pea hulls, grain and oat brans (Sosulski and Wu 1988), and various distillers' grain products from wheat and barley (Rasco *et al.* 1990; Rasco *et al.* 1989a,b,c; Rasco *et al.* 1987b; Dawson *et al.* 1984; Morad *et al.* 1984) have been recently reported. Specifically, this paper describes the development and evaluation of fiber ingredients manufactured by enzymic and yeast fermentation of whole grain triticale, and reports select nutritional and functional properties of these ingredients.

MATERIALS AND METHODS

Production of Triticale Ingredients

Distillers' dried grain materials were made from whole ground triticale (mixed cultivars, grown in Washington State, 1986 crop year) as described in Rasco *et al.* (1987a) with modifications for the production of washed distillers' grain products (Rasco 1988). Rinsed triticale materials were prepared by suspending the enzyme fermented mash in two volumes of water, and recovering the insoluble solids along with a portion of the soluble and insoluble solids by filtration.

Neutralized distillers' grain products were made by neutralizing the yeast fermented mash (pH 3.5 to 4.2) to pH 6.5 to 7.0 with a slurry of calcium oxide and sodium hydroxide (1:1 w/w). Fermented triticale mash was blended with variable amounts of whole wheat flour to improve the sheeting properties of the material as it was dried. Wet grains and wet grains plus whole wheat flour blends were dried on a pilot scale double drum dryer (Model ALC-4, 6 in × 8 in, Blaw-Knox Food and Chemical Equip. Div., Buffalo, NY) operated at a steam pressure of 275 to 301 kPa (40.4 to 44.3 psi) and drum speeds ranging from 1.3 to 6.9 rpm. The drum spacing was 0.2 mm.

Proximate Analysis

The proximate composition of the fiber ingredients was conducted using AACC (1986) methods: moisture (44.15), crude fat (30.25), ash (08.01). Protein nitrogen was determined by the method of Hach *et al.* 1985. Neutral detergent fiber, as an estimate of total dietary fiber, was measured using the method of Goering and van Soest (1970) as modified by Dong and Rasco (1987).

Glucose and Starch Analysis

A modification of AOAC Method 14.074 was used for starch hydrolysis. A 2% (w/v) solution of amyloglucosidase (Alltech, Inc., Lexington, KY) was employed for enzymic hydrolysis of starch. Following hydrolysis, the supernate was recovered by vacuum filtration through Whatman 41 filter paper, diluted to 25 to 500 μg glucose/mL in mobile phase (0.01 N H_2SO_4), and stored at −30°C until analyzed by HPLC.

The free glucose content of the fiber samples was determined by extracting samples in distilled, deionized water (1:20 (w/v)) for 30 min at room temperature in a metabolic shaking incubator (approximately 90 osc/min). The supernate was recovered by vacuum filtration and diluted for analysis as described above.

Prior to HPLC analysis, aliquots were filtered through 0.2 μ Nylon 66 filters (Alltech Associates, Deerfield, IL). The HPLC apparatus consisted of: a pump (Model SP8700, Spectra-Physics, Houston, TX) set at a flow rate of 1 mL/min, a Rheodyne Model 7125 injection valve (Bio-Rad, Richmond, CA) equipped with a fixed volume sample loop (20 μL), a column heater (Bio-Rad, Richmond, CA) set at 65°C, and a differential refractometer detector (Model 1770, Bio-Rad. Richmond, CA, RI × 4). An analytical column (AMINEX Ion Exclusion, HPX-87H, 300 × 7.8 mm, Bio-Rad Richmond, CA) and a guard column (Cation-H) were used.

To prepare glucose standards a glucose stock solution (1 mg/mL) was serially diluted in mobile phase (0.01 N H_2SO_4), and stored frozen at −20°C. The lower limit of detection for this HPLC assay was 8 μg glucose/mL. The retention time for glucose was 7.5 min.

Product Color

Tristimulus color values for the fiber ingredients and experimental breads (interior and crust color) were measured using a Colorimeter Model XL 10 CDM (Gardner Laboratory Inc., Bethesda, MD), a standard white color tile (L = 94.3, a = −1.2, b = 2.9), and a standard light source, luminescence C. Visual lightness and luminous reflectance were measured. Color analyses were conducted for single readings from samples of materials from three separate batches.

Baking Tests

Baking quality was evaluated using an optimized straight dough bread pup baking method (AACC 10–10b). Fiber ingredients from triticale were evaluated at 15% and 30% replacement levels for flour (13.0% protein). Crumb grain was rated using a three point (''satisfactory'', ''questionable'', ''unsatisfactory'') scale. Mixing properties of the fiber ingredient, flour blends were determined using a 50 g farinograph method (AACC Method 54-21, constant flour weight, variable dough weight). Loaf volume was measured by rapeseed displacement tests immediately after baking, mean values reported were for triplicate analyses from each of three loaves.

Mineral content of whole grains and fiber products

The calcium, iron and zinc content of the whole grains and fiber ingredients (Table 3) was assayed by digesting ca. 1.000 g in 20 mL concentrated nitric acid. Lanthanum chloride (0.1 g) (Sigma Chemical Co., St. Louis, MO) and 0.1 g silicon antifoam agent B (Sigma Chem. Co.) were added to aid sample digestion. Digests were cooled, filtered through ashless filter paper, quantitatively transferred to volumetric flasks, and diluted to volume with HPLC grade water. Analyses were conducted by atomic absorption (Atomic Absorption/Emission Spectrometer 151/251 AA/AE Instrumentation Laboratory Inc., Wilmington, MA) in triplicate for each of three sample digests. Soluble minerals were assayed as described by Platt and Clydesdale (1986).

In Vitro Digestibility

In vitro digestibility of ground fiber ingredients was measured as described (Dong *et al.* 1987).

RESULTS AND DISCUSSION

The proximate composition of the dried distillers' grain products and the co-dried distillers' grains/flour blends are given in Table 1. Ash content was highest

TABLE 1.
CHEMICAL COMPOSITION OF TRITICALE FIBER INGREDIENTS PRODUCED BY FERMENTATION

Sample	Flour[1] Solids	Moisture	Ash	Crude Lipid	Nitrogen	Neutral Detergent Fiber	Starch	Free Glucose
		% dry weight basis (dwb) X ± SD						
Triticale	NA	10.41±0.08	1.63±0.09	1.14±0.03	1.97±0.02	15.9±1.2	75.1±1.1	0.4±0.1
Washed Distillers' Grains (WDG)	0	8.12±0.08	1.95±0.09	2.82±0.09	4.79±0.19	53.7±3.1	26.6±1.1	0.6±0.1
	41	9.67±0.04	1.88±0.04	2.02±0.04	3.86±0.19	35.8±1.4	32.4±4.3	ND
	31	10.6±0.14	1.84±0.15	2.24±0.03	4.07±0.07	38.1±1.1	27.4±1.1	ND
Distillers' Dried Grains (DDG), acidic	0	8.25±0.03	2.59±0.03	2.27±0.10	3.78±0.09	34.8±0.8	28.1±2.2	ND
	20	10.34±0.11	6.20±0.12	1.06±0.01	3.93±0.31	33.7±3.4	28.5±2.2	ND
	31	9.60±0.17	5.76±0.19	1.25±0.02	3.81±0.11	27.5±1.4	36.8±2.2	ND
Distillers' Dried Grains, neut.	0	9.72±0.07	6.00±0.08	1.59±0.08	3.86±0.14	35.4±2.5	26.3±1.1	ND
Distillers' Dried Grains w/ Solubles (DDGS), neut.	0	8.71±0.08	6.54±0.09	1.36±0.09	3.54±0.11	28.4±0.76	34.8±4.3	0.4±0.1

NA = not applicable
ND = not determined
neut. = neutralized, for production of these materials, see text.
[1]Ground whole wheat added, % by weight. Composition of whole wheat was: 9.9 ± 0.5% water, 1.81 ± 0.1% ash (dwb), protein nitrogen (%N × 5.7) 14.3 ± 0.37%, crude lipid 1.6 ± 0.1%.
Values reported are the mean and standard deviation for triplicate analyses for three samples of each material (n = 3).

in the products that were neutralized prior to drying. The crude lipid content for all these products was low, less than 2.5% (dwb). The increase in nitrogen content of the triticale distillers' grain materials compared to the starting grain (180–240%) was lower than the approximately 270% increase previously reported for wheat distillers' grain materials (Rasco *et al.* 1987a). The smaller increase in nitrogen content of triticale distillers' grains compared to wheat distillers' grains was most likely due to incomplete conversion of starch to glucose during enzymic liquefaction. After fermentation, the amount of nonfiber carbohydrate remaining in distillers' grain products is extremely low for higher protein wheats (2.4 to 2.5% protein nitrogen, (dwb)), but can be as high as 22% of the solids content for fermented lower protein red and white wheats (1.1% protein nitrogen, (dwb)) (Dong and Rasco 1987).

The level of neutral detergent fiber (NDF) in triticale distillers' grain materials was similar to that previously reported for wheat distillers' grain products (Dong and Rasco 1987; San Buenaventura *et al.* 1987; Rasco *et al.* 1989b). The washed distillers' grain product with no flour solids added contained the highest percentage of NDF (53.7%, dwb). Although the level of free glucose in the yeast fermented triticale products was low (0.4 to 0.6% dwb), there was still enough glucose present to contribute to browning reactions, making these materials difficult to dry.

Distillers' grains with solubles are difficult to dry because of the low solids content. The fermented mash is $\leq$ 10% solids and contains significant amounts of the unfermented sugar, limit dextrins, a high content of volatile and nonvolatile organic acids, ethanol, and other fermentation products. Up to 25% of the protein in the mash can be water soluble (Rasco *et al.* 1989b). Removal of a portion of the soluble solids by filtration before drying increases the solids content of the mash to 15–18%. However, this filtered mash is still difficult to dry without backmixing dried product ($\geq$ 90% solids) with the low solids dryer feed unless drum drying or freeze drying are employed. To improve the drying rate and potentially the flavor, color, and functional properties of the fiber product, filtered mash was blended with 0–41% ground whole flour (w/w) prior to drying. The composition of these materials is given in Table 1. Drying rate increased linearly and in a predictable manner when ground whole wheat was added to the fermented mash. The calculated regression equation for drying the mash-flour blends was:

$$\text{drying rate (g/min)} = 0.19\ x + 6;$$
$$\text{where } x = \% \text{ added ground whole wheat flour solids } (r^2 = 0.87).$$

Compared to the drying rate of fermented mash to which no flour solids were added, the rate of drying the mash solids increased by 20% at the 20% flour addition level, 58% at the 31% flour addition level, and 98% at the 41% flour

addition level. The drying rate for the flour and mash blends on an atmospheric double drum dryer were: 3.0 mg/cm^2/min for 0% added flour solids, 3.3 mg/cm^2/min 20% added flour solids, 5.0 mg/cm^2/min for 31% added flour solids, and 7.2 mg/cm^2/min for 41% added flour solids.

Values for the *in vitro* protein digestibility of whole grains and distillers' dried grains are shown on Table 2, along with selected PER values from the literature. The apparent protein quality of triticale and triticale distillers' grains were similar to those for whole wheat and wheat distillers' grains. The protein digestibility of the triticale distillers' grains and barley DDGS, milo DDGS and wheat bran were comparable. The protein digestibility of oat fiber was significantly lower than the other materials tested.

The level of total and soluble iron, calcium, and zinc are presented in Table 3 for triticale, triticale distillers' grain products, white wheat DDGS, wheat bran, and oat fiber. Soluble mineral content is often used to provide an index of the bioavailability of the nutrient mineral. Triticale DDG and DDGS had a signif-

TABLE 2.
PROTEIN QUALITY ASSESSMENT OF WHOLE GRAINS AND FIBER INGREDIENTS

Product	PER	Protein Digestibility (in vitro, %) X ± SD
Triticale, Whole[a]	1.2-1.5[a]	81.0±0.4[A]
Distillers' Dried Grains	--	77.7±0.3[B]
Wheat, Whole[a,b]	0.83-0.85[a], 1.44[b]	78.0-88.9[AC]
Wheat, DDGS[c]	0.2-0.6[c]	80-81[AC]
Barley, Whole	--	74.3±0.2[B]
Barley DDGS	--	75.3±0.2[B]
Milo, Whole	--	69.7±0.2[C]
Milo DDGS	--	75.7±0.6[B]
Oat Fiber	--	48.3±0.3[D]
White Wheat Bran	--	75.2±0.9[B]

[1]Protein digestibility by *in vitro* protein digestibility enzyme assay. Values are for neutralized drum dried product (DDG) and are the mean and standard deviation for three analyses.
[a]Data from Kies and Fox (1985).
[b]Data from Satterlee *et al.* (1976). Value reported is adjusted PER.
[c]Data from Dong *et al.* (1987).
A–D Values with the same superscript were not significantly different at $p > 0.05$ using one-way analysis of variance and Duncan's New Multiple Range test (Zar 1984).

TABLE 3
COMPARISON OF THE TOTAL AND SOLUBLE IRON, CALCIUM, AND ZINC CONTENT OF TRITICALE FIBER INGREDIENTS WITH FIBER INGREDIENTS FROM WHEAT AND OATS, UG/G (DWB)

	Fe		Ca		Zn	
Sample	Total	Soluble	Total	Soluble	Total	Soluble
	X ± SD					
Triticale,						
Whole Ground	83.4±0.5[a]	5.1±0.1[a]	310±5	23.6±0.8	76.7±1.5	2.7±0.1
Distillers' Dried Grains (DDG), acidic						
(no flour added)	96.2±1.2[b]	10.9±0.1	612±4	90.3±1.7[a]	65.8±1.2	7.0±0.1
Distillers' Dried Grains w/ Solubles DDGS, neutralized						
(no flour added)	70.4±1.3[c]	7.8±0.2	1300±9	290±2	68.0±1.9	4.5±0.2
White Wheat DDGS	61.5±0.6[d]	5.3±0.1[a]	1980±20	87.5±2.5[a]	92.7±1.2	6.5±0.3
White Wheat Bran	46.3±1.1[e]	4.5±0.8[a]	42.3±3.5	2.8±0.8	127±2	1.9±0.2[a]
Oat Fiber	51.7±3.7[f]	2.9±0.6	2320±30	16.7±1.1	22.4±1.3	1.9±0.2[a]

[a-c] Values with the same superscripts within the same column were not significantly different ($p < 0.05$) using analysis of variance and Duncan's New Multiple Range Test ($n = 3$) (Zar 1984).

Source of ingredients: triticale, whole (mixed cultivares grown in Washington State, 1986 crop year), triticale dried grains (see text), white wheat DDGS from soft white winter wheat Hill 81 cultivar (for production see text), white wheat bran (Fisher Mills, Harbor Island, WA), oat fiber (No. 757, D.D. Williamson and Co., Inc., Modesto, CA).

icantly higher total and soluble Fe content compared to the other fiber ingredients tested. The % soluble Ca and Zn was higher in triticale DDG and DDGS than either wheat or oat fiber products. The amount of iron (both total and soluble) was highest in the triticale distillers' dried grains; the lowest total iron in white wheat bran, and the lowest soluble iron content in oat fiber, white wheat bran, and white wheat DDGS. The calcium content was highest in the fiber ingredients to which calcium had been added for neutralization, and also in the oat fiber material tested in this study (neutralized distillers dried grains (DDG) or distillers' dried grains with solubles (DDGS).

The mixing properties of blended flour containing 15% ground fiber ingredients with all-purpose flour are provided in Table 4. Triticale dried distillers' grains (DDG) had a higher water absorption than milo DDG, and a lower water ab-

TABLE 4.
MIXING PROPERTIES BY FARINOGRAPH OF DOUGHS CONTAINING VARIOUS FIBER INGREDIENTS*

Product	Substit. Level (w/w)	Water Absorption (%)	Devel. Time (min.)	Stability (min.)
Flour, All Purpose	--	73	6	10.5
Distillers' Dried Grains, DDG				
Triticale, DDG	15	71.5	6.5	10
White Wheat, DDG	15	78.5	5.5	5.5
Red Wheat, DDG	15	78	8.5	12
Barley, DDG	15	76	5.5	11
Milo, DDG	15	60	6	7.5
Brans				
White Wheat	15	79	7	10
Rice	15	62	4	7
Oat Fiber	15	73	8.5	7.5
Prune Fiber	15	77	5	8

* Reported values are for duplicate experiments using neutralized, drum dried product.

Source of Ingredients: Flour (all purpose, Gold Medal, Pillsbury Co., Mnpls, MN); DDG, prepared as described in text from soft white winter wheat (Hill 81 cultivar), red wheat (blend of Fremont, Pilot and Bannock), barley (Steptoe Cultivar), milo and triticale (mixed cultivars); white wheat bran (Fisher Mills, Harbor Island, WA), rice bran (Protex 20-5, Riviana Foods, Inc., Houston, TX), oat fiber (Better Basics Oat Fiber, No. 757, D.D. Williamson and Co., Inc., Modesto, CA), prune fiber (Mayfair Packing Co., San Jose, CA). All fiber ingredients were ground so 100% passed through a 16-mesh screen. DDG products were dried by drum dryer, no flour added (see text).

sorption value than red wheat, white wheat, or barley DDG, a development time intermediate between wheat and barley DDG, and a stability similar to red wheat and barley DDG but higher than that of white wheat DDG. The development time and stability for triticale DDG doughs were similar to the doughs containing white wheat bran. Triticale DDG had a similar water absorbance value to oat fiber but a shorter dough development time. Rice bran doughs had a low water absorbance and short development times, less than for the control. Doughs containing prune fiber had high farinograph water absorbance value and a development time similar to the control. Instrumental color measurements indicate that triticale DDG most closely resembles white wheat bran, white wheat DDG, and oat fiber (Table 5). Breads containing triticale DDG were darker than the control (Table 6) but were similar in color to breads containing comparable levels of wheat distillers' grains or white wheat bran (Rasco *et al.* 1987b).

The loaf volume and crumb grain of yeast-raised breads containing triticale distillers' grains in either a ground (100% through 16 mesh) or flake (approx. 50% through 8 mesh) at 15 and 30% (w/w) flour replacement level are provided in Table 7. Comparative data for white wheat DDG and bran are included. Triticale DDG had baking characteristics similar to white wheat DDGS or wheat bran, exhibiting a 14–18% reduction in loaf volume at a 15% (w/w) fiber replacement level. The crumb grain of the breads containing the ground triticale DDG at the 15% substitution level was satisfactory, but breads containing the

TABLE 5.
TRISTIMULUS COLOR VALUES FOR DISTILLER'S GRAINS AND OTHER FIBER INGREDIENTS

Product*	Fiber Ingredient Color		
	L	a	b
	X ± SD		
Flour, All Purpose	85.1 ± 1.6a	0.5 ± 0.1a	0.7 ± 0.5a
Distiller's Dried Grains, DDS			
Triticale, DDG	61.1 ± 1.6	0.4 ± 0.3	16.9 ± 0.2
White Wheat, DDG	61.1 ± 0.6	2.8 ± 0.1	21.0 ± 0.5
Red Wheat, DDG	59.0 ± 0.1	3.1 ± 0.1	18.5 ± 0.1
Barley, DDG	56.7 ± 0.4	4.2 ± 1.4	17.0 ± 1.8
Milo, DDG	45.3 ± 0.6	6.3 ± 0.1	14.7 ± 0.3
Brans			
White Wheat	67.3 ± 0.1	-0.4 ± 0.1	16.5 ± 0.2
Rice	53.6 ± 0.2	3.8 ± 0.1	18.2 ± 0.1
Oat Fiber	64.2 ± 0.9	0.1 ± 0.4	18.1 ± 0.4
Prune Fiber	24.1 ± 0.1	17.2 ± 0.1	8.1 ± 0.1

*Reported values are for single readings from samples from three lots of material. Refer to text and Table 4 for product descriptions.

TABLE 6.
CRUST AND INTERIOR COLOR OF BREADS CONTAINING TRITICALE DISTILLERS' GRAIN INGREDIENTS

Product	n	Interior Color				Crust Color			
		L	a	b	ΔE[1]	L	a	b	ΔE
		X ± SD							
Control (no fiber)	3	65.4±4.9	-0.8±0.2	14.5±0.7	--	47.2±3.7	8.2±0.8	18.8±1.1	--
Triticale DDG:									
15%, ground	3	52.3±4.3	1.3±0.2	14.4±0.3	13	37.5±4.5	8.1±1.9	16.8±1.5	10
15%, flake	3	52.4±2.2	0.8±0.4	14.6±0.5	13	37.2±3.6	6.3±1.5	15.5±1.7	11
30%, ground	3	46.9±1.4	1.5±0.3	14.4±0.6	19	36.6±2.1	5.0±2.8	15.6±1.7	12
30%, flake	3	47.8±1.0	0.9±0.6	14.3±0.9	18	36.1±3.2	4.8±2.1	16.0±1.5	12

[1] Color difference relative to control.

n = number of samples. Mean and standard deviations are for single reading for different samples.

TABLE 7.
LOAF VOLUME AND CRUMB GRAIN OF BREADS CONTAINING TRITICALE OR WHEAT DISTILLERS' GRAINS OR BRAN

Product	Loaf Volume (ml) X ± SD	Crumb Grain Score
Control	850±70	S
Triticale DDG, 15%		
Ground	720±80	S-Q
Flake	700±35	S
Triticale DDG, 30%		
Ground	605±50	Q
Flake	650±60	Q-U
White Wheat DDG, 15%		
Ground	750±25	S
Flake	720±40	S
White Wheat Bran, 15%		
Flake	730±40	Q-S

Values reported are means for two experiments, three loaves per experiment, straight dough method (n = 6).

Triticale DDG used was the neutralized, drum dried product (see text). Crumb Grain Scores: S = Satisfactory, Q = Questionable, U = Unsatisfactory.

triticale ingredient at the 30% substitution level had a 24 to 30% reduction in loaf volume relative to the control, and a questionable to unsatisfactory crumb grain.

These results suggest that triticale distillers' grains may be somewhat less suitable than white wheat distillers' grains when incorporated at levels greater than 15% (flour replacement (w/w) into bread products.

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EFFECTS OF TUMBLING SPEED AND CUMULATIVE REVOLUTIONS ON RESTRUCTURED HAMS' QUALITY

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ABSTRACT

Effects of tumbling speed (15 or 25 rpm) and cumulative revolutions of the tumbler (3000, 6000 or 9000) on the quality of restructured hams were investigated. These variables had no significant effect on shrinkage and water holding capacity. However, products processed at 25 rpm and 3,000 revolutions were significantly harder, gummier, and chewier than other treatments. The hams processed at 25 rpm were significantly darker and chewier compared to the ones processed at 15 rpm as perceived by the taste panelists. Hams processed at 3,000 or 9,000 revolutions were the most tender. Overall, all the processing schedules resulted in acceptable products as judged by the sensory panel.

INTRODUCTION

An essential part in restructuring is the ability to bind pieces or chunks of meat together which upon cooking will resemble a whole muscle product. In restructured meat products, salt soluble protein extraction to the surface is an important step that affects binding strength. The addition of mechanical action (such as massaging or tumbling) assists in extracting the proteins which form a sticky surface responsible for binding during cooking.

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Tumbling involves the physical process of rotating the meat in a drum; thus transferring kinetic energy and causing alterations in muscle tissue. On the other hand, massaging is less rigorous and involves meat pieces rubbing other pieces and the surface of the drum (Cassidy *et al.* 1978). However, both tumbling and massaging achieve the same functions: (1) increased distribution of cure ingredients, and (2) increased extraction of salt soluble protein to the surface of meat (Ockerman *et al.* 1978).

Tumbling has been shown to effectively promote cohesion of the pieces during cooking, enhance tenderness, insure juiciness, develop a uniform product with desirable slicing characteristics and increase yield (Cassidy *et al.* 1978; Chow *et al.* 1986; Gillett *et al.* 1981; Krause *et al.* 1978). In the presence of high levels of salt and/or phosphate, tumbling can provide even more pronounced results (Siegel *et al.* 1978; Cassidy *et al.* 1978). However, an increased consumer concern over the dietary sodium effect is forcing the industry to search for ways to reduce the sodium content in meat products (Barbut and Findlay 1989). Therefore, better understanding of the physical processes involved in extracting the meat proteins is desired.

Adequate tumbling is an important factor in manufacturing high quality restructured products. Since, it directly affects the texture and the appearance of the product. Too little tumbling/mixing results in a product that is crumbly with a soft texture. On the other hand, too much mixing, or over-extraction of myofibrillar proteins, results in a rubbery product with a tough skin. Adequate mixing is difficult to achieve, in part due to the differences in protein extractability from various muscles, and in part because of the lack of understanding of the binding mechanism. Thus, the objective of this study was to investigate the effects of tumbling speeds and cumulative revolutions of the tumbler on the quality of restructured ham.

MATERIALS AND METHODS

Experimental Design

A 2 × 3 × 2 factorial randomized block design involving two replications was used to study the effects of tumbling speed (Speed = 15 and 25 rpm) and cumulative revolutions (3000, 6000, and 9000 revolutions) on a restructured ham containing 2% NaCl.

Tumbling schedule composed of 3 stages: tumbling, resting, and second tumbling. Table 1 shows the tumbling cycle and time used in the treatments. The second tumbling time and the overall tumbling time were held constant for all the treatments at 1.5 h and 12 h, respectively.

TABLE 1.
TUMBLING CYCLE AND TIME REQUIRED IN DIFFERENT TREATMENTS

	Tumbling Time (min)					
Treatment	First Cycle	Rest	Second Cycle	Total Tumbling Time in 12 h	rpm	REV
1	110	520	90	200	15	3000
2	310	320	90	400	15	6000
3	510	120	90	600	15	9000
4	30	600	90	120	25	3000
5	150	480	90	240	25	6000
6	270	360	90	360	25	9000

REV = cumulative revolutions of the tumbler
rpm = revolutions per min of the tumbler

Product Preparation

Fresh boneless pork muscles (semimembranosus, adductor, biceps-femoris, and semitendinosus) were ground through a kidney plate (Hobart, Don Mills, Ontario), and pork fat was ground through a 3.2 cm plate. The ground pork was mixed in a paddle-type mixer (Lasar Mfg. Co., Butcher Boy, Model 150, Los Angeles, CA) for 15 min to ensure raw material homogeneity. Then 1.5 kg ground pork was removed randomly from the mixer for proximate analysis. These samples were mixed and reground three times through a 5 mm plate. Similarly, 1 kg of pork fat was randomly collected for proximate analysis which was performed in duplicate (AOAC 1980). The lean pork composition was: 72.7% moisture, 22.6% protein, 5.1% fat, and 1.1% ash. Pork fat contained 80.9% fat, 15.6% moisture, 4.4% protein, and 0.1% ash. The meat and fat were packaged in polyethylene bags and frozen (-20°C) for up to 4 weeks. The meat was thawed for 2 days at 2°C and the fat was reground, while still partially frozen, once through a 5 mm plate to obtain small fat particles. Each treatment was formulated to contain 10% fat (2.2 kg lean pork and 153.2 g fat). The curing solution (15%) was based on the meat block mass and contained 2% NaCl, 0.33% sugar, 0.25% sodium tripolyphosphate, 0.15% black pepper, 0.04% nutmeg, 0.055% sodium erythorbate, and 0.012% sodium nitrite.

All the raw materials were placed in a Table Top Tumbler (Lyco, model 40, Columbus, WI) under vacuum (68 kPa abs.) and tumbled intermittently at 2 °C. The tumbled meat was stuffed into two 76 mm diameter Teepak fibrous, coated with plastic, casings (Teepak, Oak Brook, IL) using a hand operated stuffer

(A.M.B., Bologna, Italy). The restructured hams were cooked in a steam kettle (Groven Mfg. Co., model N-60 SP, Elk Grove Village, IL) maintained at 75 ± 2°C until an internal temperature of 70 ± 1°C was reached. Internal temperature was monitored by a digital thermocouple (Taylor, model 9200J, Sybron, NC) placed at the geometric center of the hams. After cooking, hams were cooled in an iced water bath for 30 min and then stored in a cooler (2°C) for 10 to 12 h prior to further analysis.

Shrinkage (SH) After cooling, the ham rolls were sliced in half to allow the draining of retained juice for 45 min. Shrinkage was calculated by:

$$[1 - (\text{mass after cooking/mass before cooking}] \times 100$$

Color. A Spectroguard color system (Pacific Scientific Company, model 96, Silver Spring, MD) was used to measure the color of six freshly cut surfaces from each cooked ham. The Hunter Color Lab. scale parameters of "L" (surface reflectance, degree of whiteness), "a" (intensity of the red color), and "b" (intensity of the yellow color) were determined.

Water Holding Capacity (WHC). The centrifugal method of Bouton *et al.* (1971) was used to determine WHC of six replications per treatment.

Texture Profile Analysis (TPA). The Instron Universal Testing Machine (model 4204) was used to determine the texture profiles (Bourne 1978) of the samples with 1 kN load cell. Samples (20 mm in diameter and 15 mm in height) were compressed twice to 75% of their height. Cross head and chart speeds were 20 mm/min and 100 mm/min, respectively. The following parameters were calculated: hardness (HARD, N/cm^2), cohesiveness (COH, ratio), elasticity (ELAST, cm), gumminess (GUM, N/cm^2), and chewiness (CHEW, N/cm). Eight replications were used. Samples were evaluated 12 h after cooking.

Warner Bratzler Shear (WBS). A single blade WBS was used to measure the maximum force (g) required to shear the cooked samples (Voisey and Larmond 1974) using the same dimension as used for the Textural Profile Analysis test.

Sensory Evaluation. The taste panel was composed of 13 semi-trained judges. Sensory evaluations were carried out by graduate students and technicians of the Food Science Department who had broad experience in sensory evaluation of food products and were trained to evaluate the restructured ham. The evaluation took place in a room equipped with individual booths under daylight conditions. Water was available for the individual judges to rinse their mouths. Round ham samples (4 mm thick) were placed on a white paper plate and coded with a randomized three digit number. Each judge evaluated the color intensity (1 = very pale, 15 = very dark), tenderness (1 = tough, 15 = tender), juiciness (1 = dry, 15 = juicy), chewiness (1 = chewy, 15 = not chewy), off-flavor, (1 = pronounce off-flavor, 15 = no off-flavor), and overall accept-

ability (1 = dislike, 15 = like) of the product. The ballot used consisted of 15 cm long horizontal lines (Stone *et al.* 1974). Each panelist marked the scale between these two endpoints. Results were obtained by measuring the distance from the left side of the scale to the judge's rating in cm.

Statistical analyses were conducted using the Statistical Analysis System (SAS 1985) on an IBM 3081D mainframe computer. Analysis of variance (ANOVA) was used to test the effects of 6 treatments, tumbling speed (SPEED) and cumulative revolutions. If ANOVA showed a significant difference, means were separated by using Duncan's test. The SAS procedure CORR was used to compute correlation coefficient between variables.

RESULTS AND DISCUSSION

Proximate Composition

The ANOVA tests indicated no effect of any variable on proximate composition i.e., moisture, ash, protein and fat contents. These are in agreement with Ghavimi *et al.* (1987), Pepper and Schmidt (1975) and Booren *et al.* (1981) who indicated that tumbling speed and tumbling time had no effect on the chemical composition of restructured beef products.

Shrinkage (SH) and Water Holding Capacity (WHC)

The ANOVA showed that speed, revolutions, and speed × revolutions interaction had no significant effect on SH and WHC. These are in agreement with Siegel *et al.* (1978) who used 10% pump in restructured ham and reported that different tumbling time had no effect on product shrinkage. In addition, Chow *et al.* (1986) and Motycka and Bechtel (1983) indicated that different tumbling times and methods (intermittent vs continuous) had no influence on the WHC of raw product. However. our results do not agree with Gillett *et al.* (1981) who indicated that cook shrinkage decreased as massaging time increased from 0 h (0 revolutions) to 20 h (6,000 revolutions). The disagreement between these two studies was probably due to different cure level injected to the product (30% pump vs 15% pump in the present study). Overall, 15 rpm and 3,000 revolutions were sufficient to achieve the optimum shrinkage and WHC in the restructured ham within the experimental range investigated.

The Pearson's correlations suggested that as water holding capacity decreased, shrinkage increased, which confirmed the findings of Rejt *et al.* (1978) for massaged and nonmassaged meat.

Hunter Color Parameters (L, a, b)

Treatment means comparison (Tables 2 and 4) indicated that the treatments significantly affected surface reflectance (L) only in treatments 4 (25 rpm and

TABLE 2.
SUM OF SQUARES FROM THE ANALYSIS OF VARIANCE FOR COLOUR AND TEXTURAL PARAMETERS

Source	df	'a'	'b'	Hardness	Elasticity	Gumminess	Chewiness
Replication	1	1.03	0.28*	0.4	0.02**	0.6	4.8**
Treatment	5	9.32*	0.60	233.4***	0.01	40.1**	24.8***
Speed X revolutions	2	4.55	0.18	10.6	9 E-4	2.8	2.3
Speed	1	2.45*	0.19	81.8***	0.01**	12.6**	11.4***
Revolutions	2	2.32	0.23	141.0***	2 E-3	24.7**	11.1**
Error	5	2.02	0.25	20.4	8 E-3	7.3	2.2
Total	11	12.37	1.13	254.2	0.04	48.0	31.8

df=degree of freedom, 'a'=redness, 'b'=yellowness
* $0.01 \leq P < 0.05$; ** $0.05 \leq P < 0.01$; *** $P \leq 0.01$

TABLE 3.
SUM OF SQUARES FROM THE ANALYSIS OF VARIANCE FOR SENSORY ATTRIBUTES

Source	df	Color	Tenderness	Juiciness	Chewiness
Replication	1	0.2	0.02	0.04	0.49
Treatment	5	11.5***	6.25**	3.33	2.99
Speed	1	1.8**	0.53*	2.38*	2.64**
Revolutions	2	3.9**	1.52**	0.49	0.22
Speed X revolutions	2	5.8***	4.20***	0.46	0.13
Error	5	0.8	0.64	1.93	1.34
Total	11	12.5	6.90	5.30	4.82

* $0.1 \leq P < 0.05$; ** $0.05 \leq P < 0.01$; *** $P \leq 0.01$
df=degree of freedom, color (1 = very pale, 15 = very dark), tenderness (1= tough, 15 = tender), juiciness (1 = dry, 15 = juicy), and chewiness (1 = chewy, 15 = not chewy).

TABLE 4.
DUNCAN'S TEST RESULTS FOR DIFFERENT TEXTURAL AND SENSORY PARAMETERS WITH RESPECT TO TREATMENTS

Treatment		'L'	'a'	Hardness, N/cm^2	Gumminess, N/cm^2	Chewiness, N/cm	Sensory	
rpm	REV						Color	Tender-ness
15	3000	59ab	11.1ab	47ab	11.6abc	6.2bc	6.7bc	6.9cd
15	6000	61ab	9.7b	41c	10.3bc	5.1c	5.6d	7.9abc
15	9000	60ab	12.1a	39c	9.2c	4.8c	6.3cd	7.5bcd
25	3000	58b	10.6ab	52a	14.3a	8.8a	7.6ab	8.2ab
25	6000	60ab	10.1b	49a	13.1ab	7.7ab	8.0a	6.6d
25	9000	62a	9.6b	43bc	9.8c	5.5c	5.3d	8.7a

Means followed by identical letters, in the same column, are not significanthly different at 5% level.

'L'=lightness, REV = revolutions, and 'a'=redness.

3000 revolutions) and 6 (25 rpm and 6000 revolutions). Treatment 3 (15 rpm and 9000 revolutions) had the highest redness ('a'), and treatments 2 (15 rpm and 6000 revolutions), 5 (25 rpm and 6000 revolutions) and 6 (25 rpm and 9000 revolutions) had lower values. This suggested that both tumbling speed and revolutions are important in providing desired color to the hams. These results are in partial agreement with Chow *et al.* (1986), and Motycka and Bechtel (1983) who used only the tumbling time as variable, and indicated that it had no influence on color in cured pork shoulder and ham.

Warner Bratzler Shear (WBS) and Texture Profile Analysis (TPA)

The ANOVA showed that speed, revolutions, and speed × revolutions interaction did not significantly affect WBS. These results are in agreement with Chow *et al.* (1986) and Motycka and Bechtel (1983) who indicated that different tumbling time did not affect ham tenderness.

The ANOVA indicated that the cohesiveness (COH) was the only parameter that was not significantly affected by tumbling speed, revolutions, and speed × revolutions interaction (data not shown). The speed significantly affected hardness, elasticity, gumminess, and chewiness (Table 2). The tumbler revolutions significantly affected hardness, gumminess and chewiness. There was no significant effect of speed × revolutions interaction on any of the Texture Profile Analysis (TPA) parameters. The Duncan's test (Table 5) showed that the 25 rpm treatment resulted in significantly higher hardness, elasticity, gumminess and chewiness than those of 15 rpm treatment. This indicates that the use of higher speed (25 rpm) contributed to the firmness (higher hardness) and elasticity of the product. This would be expected since vigorous tumbling at 25 rpm caused an increase in cell disruption and extraction of more myofibrillar proteins. Upon heating, these myofibrillar proteins are coagulated and contribute to a rigid and firm cooked product structure. Gumminess and chewiness are directly related to hardness and elasticity, therefore these were also significantly affected by tumbling speed.

All revolutions levels significantly affected hardness (Table 6). Hams processed at 9,000 revolutions had significantly lower gumminess and chewiness than those processed at 3,000 and 6,000 revolutions. These results suggested that as the tumbler revolutions increased above 6,000; hardness, gumminess and chewiness decreased. Rust and Olson (1988) stated that the higher tumbling action produces more tender product. This agreed with the present study which indicated that as the cumulative tumbling revolutions increased, hardness decreased. Cassidy *et al.* (1978) stated that increased tumbling caused an increase in cell membrane disruption in both surface and deep muscle regions and thus enhanced tenderness. Similar findings were observed by Chow *et al.* (1986) and Booren *et al.* (1981) who indicated that as total tumbling time increased, meat

TABLE 5.
DUNCAN'S TEST RESULTS FOR TEXTURAL AND SENSORY PARAMETERS WITH RESPECT TO SPEED

Speed, rpm	Hardness, N/cm^2	Elasticity, cm	Gumminess, N/cm^2	Chewiness, N/cm	Sensory	
					Color	Chewiness
15	42.6b	0.52b	10.4b	5.4b	6.2b	6.7b
25	47.8a	0.58a	12.4a	7.3a	7.0a	7.6a

Means followed by identical letters, in the same column, are not significantly different at 5% level.

TABLE 6.
DUNCAN'S TEST RESULTS FOR TEXTURAL AND SENSORY PARAMETERS WITH RESPECT TO CUMULATIVE REVOLUTIONS

Revolutions, Number	Hardness, N/cm^2	Gumminess, N/cm^2	Chewiness, N/cm	Sensory	
				Color	Tenderness
3000	49.4a	13.0a	7.5a	7.2a	7.6ab
6000	45.2b	11.7a	6.4a	6.8a	7.2b
9000	41.0c	9.5b	5.2b	5.8b	8.1a

Means followed by the identical letters, in the same column, are not significantly different at 5% level.

tenderness increased. Since gumminess and chewiness are related to hardness, they also showed a significant effect of the revolutions.

Sensory Evaluation

The ANOVA showed that speed, revolutions, speed × revolutions interaction did not significantly affect off-flavor and overall acceptability. The Pearson correlation indicated that overall acceptance was significantly correlated with sensory color intensity ($r = -0.60$) and sensory tenderness ($r = 0.64$). These correlations suggested that products which were paler in color, and higher in tenderness were most preferred by the panelists.

The ANOVA (Table 3) showed that speed, revolutions, and speed × revolutions interaction significantly affected color. The Duncan's test (Table 4) indicated that treatment 5 (25 rpm and 6,000 revolutions) had the highest color intensity. This suggested that cumulative tumbling revolutions above 6,000 revolutions decreased color intensity. This finding agrees with Gillett *et al.* (1981) who indicated that the highest sensory-panel rating for ham color intensity and uniformity was at 6,000 revolutions.

Tumbling speed did not significantly affect tenderness (Table 3). This agrees with Ghavimi *et al.* (1987) who indicated that tumbling speeds (5, 10, 15, and 20 rpm) did not affect Allo-Kramer shear. The tenderness was significantly affected by revolutions and speed × revolutions interaction (Table 3). This indicates that tumbling speed and cumulative tumbling revolutions together influence the tenderness. Both should be considered in designing a tumbling process. In addition, the Duncan's test (Table 4) indicated that treatment 6 (25 rpm and 9,000 revolutions) was the most tender in comparison to other treatments. Thus, higher speed and maximum revolutions provided the most tender product within experimental conditions. The effects of speed > 25 rpm and revolutions > 9000 should be investigated further. A similar trend was reported by Booren *et al.* (1981) who found that sensory tenderness increased as mixing time increased from 0 to 18 min in sectioned and formed beef steaks.

Table 3 shows that tumbling speed significantly affected sensory chewiness. However, it did not significantly correlate with chewiness measured by Texture Profile Analysis. This could be due to the different interpretation of chewiness by instrument and sensory evaluation. Overall, products tumbled at 25 rpm were significantly less chewy than that at 15 rpm. The ANOVA (Table 3) also showed that none of the parameters affected juiciness at 95% level. This result agreed with Motycka and Bechtel (1983) and Chow *et al.* (1986) who indicated that tumbling time and processing method (continuous vs intermittent) did not affect sensory juiciness in ham and cured pork shoulder.

The correlations indicated that products with higher texture profile parameters (except elasticity) were rated better in color intensity by the panel. Furthermore,

products having lower cohesiveness and gumminess were rated as having lower off-flavor by the panel.

CONCLUSIONS

Restructured hams processed at 25 rpm and a cumulative revolutions of 3000 were significantly harder, gummier and chewier. The hams processed at 25 rpm were significantly darker and chewier, and hams processed at 9000 revolutions were the least gummy and chewy.

ACKNOWLEDGMENTS

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LIST OF SYMBOLS

ANOVA	Analysis of variance
df	Degree of Freedom
P	Probability level
r	Correlation coefficient
SH	Shrinkage (%)
TPA	Texture Profile Analysis
WBS	Warner-Bratzler Shear (g)
WHC	Water holding capacity

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THE EFFECT OF INTERNAL THERMAL GRADIENTS ON THE RELIABILITY OF SURFACE MOUNTED FULL-HISTORY TIME-TEMPERATURE INDICATORS

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ABSTRACT

A simple analytical expression aimed at assessing the theoretical reliability of a full-history time-temperature indicator placed on the surface of a food item as a predictor of the remaining shelf-life in the presence of heat transfer limitations within the food is obtained. Such expression, which depends on three dimensionless parameters only, can be written as a univariate function of a single parameter containing the thermal properties of the food via a suitable algebraic scaling. The derivation of the relevant formulae is based on the integration of a generic quality function across the slab-shaped food item under the assumption that the temperature on the surface of the food undergoes a sinusoidal variation with time. The analysis reported is useful because it provides a quick estimate of the effect of the thermal diffusivity of the food on the relative error associated with the use of a TTI when the activation energies of the food and the indicator are matched (as should happen in the idealistic case) under realistic environmental conditions of storage.

INTRODUCTION

It is generally agreed that the most important environmental parameter leading to quality changes during refrigerated and frozen food handling is the cumulative effect of storage time and temperature (Van Arsdel *et al.* 1969; Jul 1984; Labuza 1982). In order to assess the degree of quality loss of perishable foods, full-history time-temperature indicators (TTI's) have been developed; reviews by Schoen and Byrne (1972) and Kramer and Farquhar (1976) provided comprehensive information on patented and commercially available indicators able to monitor variations in temperature with time. These indicators are physicochem-

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ical systems which exhibit an easily monitored irreversible change in a physical property in response to the combined cumulative effect of time and temperature (Wells and Singh 1988b). The TTI's must be small, inexpensive, and easily attachable to the surface of the food or its package (Taoukis and Labuza 1989a). The usefulness of TTI's as tools for the detection of food quality changes during storage has been emphasized by Mistry and Kosikowski (1983) and Singh and Wells (1985). The information provided by TTI's on the amount of food quality left can be used to improve and tightly control the food distribution, to optimize the food product rotation at the retail level, and to replace and/or complement the open date labeling at the consumer point (Taoukis and Labuza 1989a). Confined systems undergoing a temperature-sensitive, irreversible chemical reaction or a diffusionally-controlled transformation are particularly adequate for monitoring the extent of deterioration and remaining shelf life of a food product provided that they mimick the kinetic behavior of the food quality loss in terms of similar activation energies (Taoukis and Labuza 1989a).

The use of TTI's as food quality monitors has a potentially important application in the area of perishable inventory management (Wells and Singh 1988a). Usually food items are stored in large refrigerated chambers with forced air circulation or kept in small refrigerators at home. The temperature control that has been traditionally employed in either type of storage system is an on-off thermostat triggered by a signal generated by a thermocouple. This thermostat acts as a switch in the circuit of the compression/expansion refrigeration cycle; it switches on the electric current for the compressor when the air temperature rises above a given value, and opens the circuit when the temperature falls below another, but lower, given value (Webb 1964). Such a behavior generates a measurable dead band between the set point and the two extreme states (also known as lockup or differential gap), which, although often due primarily to limitations in sensitivity of the temperature probe, avoids needless chattering of the output manipulated variable caused by noise on the temperature input signal (Shinskey 1988). Hence, on-off controllers allow the temperature to cycle in a sinusoidal fashion with an amplitude equal to the dead band and a period which is a direct function of the time constant associated with the whole controlled temperature room or refrigerator (Shinskey 1988). Despite these limitations, the on-off controller is of extremely wide application because it offers a number of advantages over alternative device controllers such as being relatively inexpensive, usually accurate and always very reliable, easily installed and adjusted, and prone to little or virtually no maintenance (Smith 1980). The most reasonable errors in food storage that are likely to occur on the long run are, therefore, those due to the aforementioned temperature fluctuations.

The effect of sinusoidal oscillations on the performance of TTI's has been the subject of a number of studies (Riboh and Labuza 1982; Chen *et al.* 1983; Labuza

and Bergquist 1983; Taoukis and Labuza 1989b). In most of these studies, however, heat transfer limitations within the food itself were not taken into account. Since the TTI placed on the top a food item will respond only to the temperature fluctuations at the top of said food item, large errors may result when the actual, overall degree of quality loss of the food is compared with its counterpart as predicted from the response of the indicator. The problem then arises as how to estimate the error involved in the common use of TTI's when the thermal inertia of the food plays a role in the temperature profile within the boundaries of the food.

It is the purpose of this paper to present the basis of a mathematical procedure that may lead to a systematic assessment of the accuracy of a TTI as a predictor of the degree of food quality loss as a function of the thermal properties of the food material and the environmental conditions of storage.

MATHEMATICAL METHODS

Loss of shelf-life in a food product is usually evaluated by the measurement of a characteristic quality parameter, which can consist of a physical, chemical, microbiological, or sensory index. The change with time, t, of a quality parameter, Y, of a food item can be usually expressed as (Taoukis and Labuza 1989a)

$$-\frac{dY}{dt} = k_{o,F} \exp\left\{-\frac{E_{act,F}}{RT\{t\}}\right\} \Psi\{Y\} \tag{1}$$

whereas the change of a suitable property, X, of the indicator can equivalently be modelled as

$$-\frac{dX}{dt} = k_{o,I} \exp\left\{-\frac{E_{act,I}}{RT\{t\}}\right\} \Xi\{X\} \tag{2}$$

Here R is the universal gas constant, and Ψ and Ξ are known functions of Y and X, respectively, while $k_{o,I}$ and $k_{o,F}$ are the preexponential factors, and $E_{act,I}$ and $E_{act,F}$ the activation energies of the Arrhenius model associated with the indicator and the food, respectively.

Following the approach initially suggested by Taoukis and Labuza (1989a), the change of the quality function (or measurable property) during a known variable temperature exposure $T\{t,z=L\}$ at the surface of a slab-shaped food item can be calculated from Eq. (2) via

$$F\{X\{t,L\}\} = -\int_{X\{0,L\}}^{X\{t,L\}} \frac{d\varsigma}{\Xi\{\varsigma\}} = k_{o,I} \int_0^t \exp\left\{-\frac{E_{act,I}}{RT\{\xi,L\}}\right\} d\xi \tag{3}$$

for the indicator, and similarly from Eq. (1) via

$$f\{Y\{t,L\}\} = -\int_{Y\{0,L\}}^{Y\{t,L\}} \frac{d\varsigma}{\Psi\{\varsigma\}} = k_{o,F} \int_0^t \exp\left\{-\frac{E_{act,F}}{R\,T\{\xi,L\}}\right\} d\xi \tag{4}$$

for the food if it were subject to exactly the same temperature history of the indicator. Here L denotes the half-thickness and z the spatial coordinate along the slab, whereas F is a function of X only and f is a function of Y only.

Defining an effective temperature, $T_{eff}\{L\}$, as the constant temperature at the surface of the food which, upon exposure to, for the same period of time, results in the same property change of a surface-mounted indicator as exposure to the variable temperature distribution, one may write

$$F\{X\{t, L\}\} = k_{o,I} \exp\left\{-\frac{E_{act,I}}{R\,T_{eff}\{L\}}\right\} t \tag{5}$$

If the surface of the food were exposed for the same period of time to the aforementioned constant temperature T_{eff}, then the approximate change in the quality parameter of the surface layer of food would be obtained from

$$f_{app}\{Y\{t,L\}\} = k_{o,F} \exp\left\{-\frac{E_{act,F}}{R\,T_{eff}\{L\}}\right\} t \tag{6}$$

The value of f_{app} will be equal to the value of f as obtained from Eq. (4) if and only if the activation energies of the food quality function and the indicator property are the same. According to the general philosophy underlying the use of TTI's, F (or a known function thereof) is measured, T_{eff} is computed employing Eq. (5), and f_{app} is calculated from Eq. (6); f_{app} is then used as an estimator of the true value of f. In order to isolate the effect of non-isothermal conditions throughout the food on the reliability of the TTI response, it will be assumed hereafter that $E_{act,I} = E_{act,F}$. Hence, Eq. (6) may be rewritten as

$$f\{Y\{t,L\}\} = k_{o,F} \exp\left\{-\frac{E_{act,F}}{R\,T_{eff}\{L\}}\right\} t \tag{7}$$

Rearrangement of Eq. (5) gives

$$T_{eff}\{L\} = \frac{E_{act,F}}{R \ln\left\{\dfrac{k_{o,I}\,t}{F\{X\{t,L\}\}}\right\}} \tag{8}$$

Combination of Eq. (7) and (8) yields

$$f\{Y\{t,L\}\} = \frac{k_{o,F}}{k_{o,I}} F\{X\{t,L\}\} \tag{9}$$

Assuming a variable temperature at the surface of the slab of the form

$$T\{t,L\} = T_m + a\{L\} \sin\left(\frac{2\pi t}{\tau}\right) \tag{10}$$

where T_m is the median temperature, a the amplitude, and τ the period of the sinusoidal fluctuation, Eq. (3) becomes (Taoukis and Labuza 1989b; Labuza 1984; Hicks 1944)

$$F\{X\{t,L\}\} = k_{o,I}\, t \exp\left\{-\frac{E_{act,F}}{R\,T_m}\right\} I_o\left\{\frac{a\{L\}\,E_{act,F}}{R\,T_m(a\{L\}+T_m)}\right\} \tag{11}$$

where I_o is a modified zero order Bessel function (Abramowitz and Stegun 1968). Upon use of Eq. (11) in Eq. (9), one gets

$$f_{pred}\{Y\{t\}\} = f\{Y\{t,L\}\} = k_{o,F}\, t \exp\left\{-\frac{E_{act,F}}{R\,T_m}\right\} I_o\left\{\frac{a\{L\}\,E_{act,F}}{R\,T_m(a\{L\}+T_m)}\right\} \tag{12}$$

where f_{pred} is the value of f to be expected if no resistance to heat transfer existed within the boundaries of the food. On the other hand, the actual quality function of the food, f_{true}, can be obtained by integrating the quality function over the whole volume of the food item (i.e., A.L, where A is the cross sectional area of the slab) according to

$$f_{true}\{Y\{t\}\} = \frac{A\displaystyle\int_0^L k_{o,F}\int_0^t \exp\left\{-\frac{E_{act,F}}{R\,T\{\xi,\varsigma\}}\right\} d\xi\, d\varsigma}{A\displaystyle\int_0^L d\varsigma} = \frac{k_{o,F}\, t \exp\left\{-\frac{E_{act,F}}{R\,T_m}\right\}}{L}\int_0^L I_o\left\{\frac{A_r\{\varsigma\}\,a\{L\}\,E_{act,F}}{R\,T_m(A_r\{\varsigma\}\,a\{L\}+T_m)}\right\} d\varsigma \tag{13}$$

where advantage was taken from the symmetry of the slab and from the fact that the ultimate response of a linear system at a generic $0 < z < L$ to a sustained sinusoidal input at $z = L$ with amplitude $a\{L\}$ is a sine wave with the same frequency, and with an amplitude $a\{z\}$ equal to $A_r\{z\}a\{L\}$ (Stephanopoulos 1984).

Combining Eq. (12) and (13), one finally obtains an estimate of the relative

error resulting from not taking heat transfer limitations into account, Er*, as given below

$$Er^* = \frac{f_{pred}\{Y\{t\}\} - f_{true}\{Y\{t\}\}}{k_{o,F}\, t \exp\left\{-\frac{E_{act,F}}{R\, T_m}\right\}} = I_o\left\{\frac{a^*\, E^*_{act,F}}{a^* + 1}\right\} - \int_0^1 I_o\left\{\frac{A_r\{\varsigma\}\, a^*\, E^*_{act,F}}{A_r\{\varsigma\}\, a^* + 1}\right\} d\varsigma \qquad (14)$$

where the dimensionless parameters are defined as follows

$$a^* = \frac{a\{L\}}{T_m} \qquad (15)$$

$$E_{act,F}{}^* = \frac{E_{act,F}}{R\, T_m} \qquad (16)$$

and

$$z^* = \frac{z}{L} \qquad (17)$$

The differential equation describing the one-dimensional unsteady heat conduction through a finite homogeneous layer reads

$$\frac{\partial T}{\partial t} = \frac{k}{\rho\, C_P} \frac{\partial^2 T}{\partial z^2} \qquad (18)$$

where k is the thermal conductivity, ρ is the mass density, and C_p is the isobaric specific heat capacity of the food material. The group $k/\rho C_p$ is usually known as thermal diffusivity, and will hereafter be denoted as α. Equation (18) is subject to the boundary condition.

$$@\ z = 0\ ,\ \forall t \geq 0\ ,\ \frac{\partial T}{\partial z} = 0 \qquad (19)$$

and to the initial condition

$$@\ t = 0\ ,\ \forall 0 \leq z \leq L\ ,\ T = T_m \qquad (20)$$

Applying Laplace transforms with respect to time, L_t , to Eq. (18)–(20), one gets (Stephenson 1973; Webb 1964)

$$G\{s\} = \frac{\mathcal{L}_t\{T\{t,z\}\}}{\mathcal{L}_t\{T\{t,L\}\}} = \frac{\cosh\left\{\sqrt{\frac{s\, L^2}{\alpha}}\, z^*\right\}}{\cosh\left\{\sqrt{\frac{s\, L^2}{\alpha}}\right\}} \qquad (21)$$

where s the independent complex variable in the Laplace domain and G{s} is the transfer function relating the behavior at a generic z to the behavior at z = L

at any time t (Webb 1964). The values for A_r are simply given by the modulus of $G\{s=2\pi i/\tau\}$, where i is the imaginary unit. Recalling Eq. (21), one then obtains

$$G\left\{\frac{2\pi i}{\tau}\right\} = \frac{\cosh\left\{\sqrt{\pi\zeta}\,(1+i)\,z^*\right\}}{\cosh\left\{\sqrt{\pi\zeta}\,(1+i)\right\}} \tag{22}$$

where the dimensionless parameter ζ is defined by the following relationship

$$\zeta = \frac{L^2}{\alpha\tau} \tag{23}$$

Use of the mathematical properties of the hyperbolic functions with complex arguments in the above equation coupled with some algebraic work finally leads to

$$A_r\{z^*\} = \sqrt{\frac{\cosh^2\left\{\sqrt{\pi\zeta}\,z^*\right\}\cos^2\left\{\sqrt{\pi\zeta}\,z^*\right\} + \sinh^2\left\{\sqrt{\pi\zeta}\,z^*\right\}\sin^2\left\{\sqrt{\pi\zeta}\,z^*\right\}}{\cosh^2\left\{\sqrt{\pi\zeta}\right\}\cos^2\left\{\sqrt{\pi\zeta}\right\} + \sinh^2\left\{\sqrt{\pi\zeta}\right\}\sin^2\left\{\sqrt{\pi\zeta}\right\}}} \tag{24}$$

Equation (14) leads to results plotted in Fig. 1.i–iv as Er* vs $E_{act,F}$* for a number of values of a* and various orders of magnitude of ζ with physical interest. The integration was performed by an adaptative double precision FORTRAN routine using the Gauss 10-point and the Kronrod 21-point rules (Doncker 1978). The modified Bessel function of the first kind, $I_0\{\upsilon\}$, was approximated by $\exp\{\upsilon\}.\Sigma_{r=0,\infty}\, a_r.T_r\{\upsilon/2-1\}$, where T_r is a Chébyshev polynomial of the first kind (Abramowitz and Stegun 1968). For large ζ, $A_r\{z^*\}$ was approximated by the asymptotic expression $\exp\{-2(1-z^*)\sqrt{(\pi.\zeta)}\}$.

It is apparent from observation of the log-log plots denoted as Fig. 1.i–iv that the approximately straight lines in each plot are parallel to each other. Furthermore, the slope of these lines remains unchanged irrespective to the value of ζ. Therefore, the slope of $\log\{Er^*\}$ vs $\log\{E^*_{act,F}\}$ must be a constant, say β_1. On the other hand, each line of each plot can be obtained from the previous one by a translation along the vertical axis of a distance proportional to $\log\{a^*\}$. Hence, the vertical intercept of the lines follows a linear dependence on $\log\{a^*\}$ characterized by a vertical intercept $Z\{\zeta\}$ and a constant slope β_2. The above conclusions allow one to obtain the following empirical expression:

$$\log\{Er^*\} = \left(Z\{\zeta\} + \beta_2 \log\{a^*\}\right) + \beta_1 \log\left\{E^*_{act,F}\right\} \tag{25}$$

Using linear regression of the slopes of the lines in Fig. 1.i-iv vs $\log\{E^*_{act,F}\}$ and linear regression of the intercepts of the same lines vs $\log\{a^*\}$, one found that

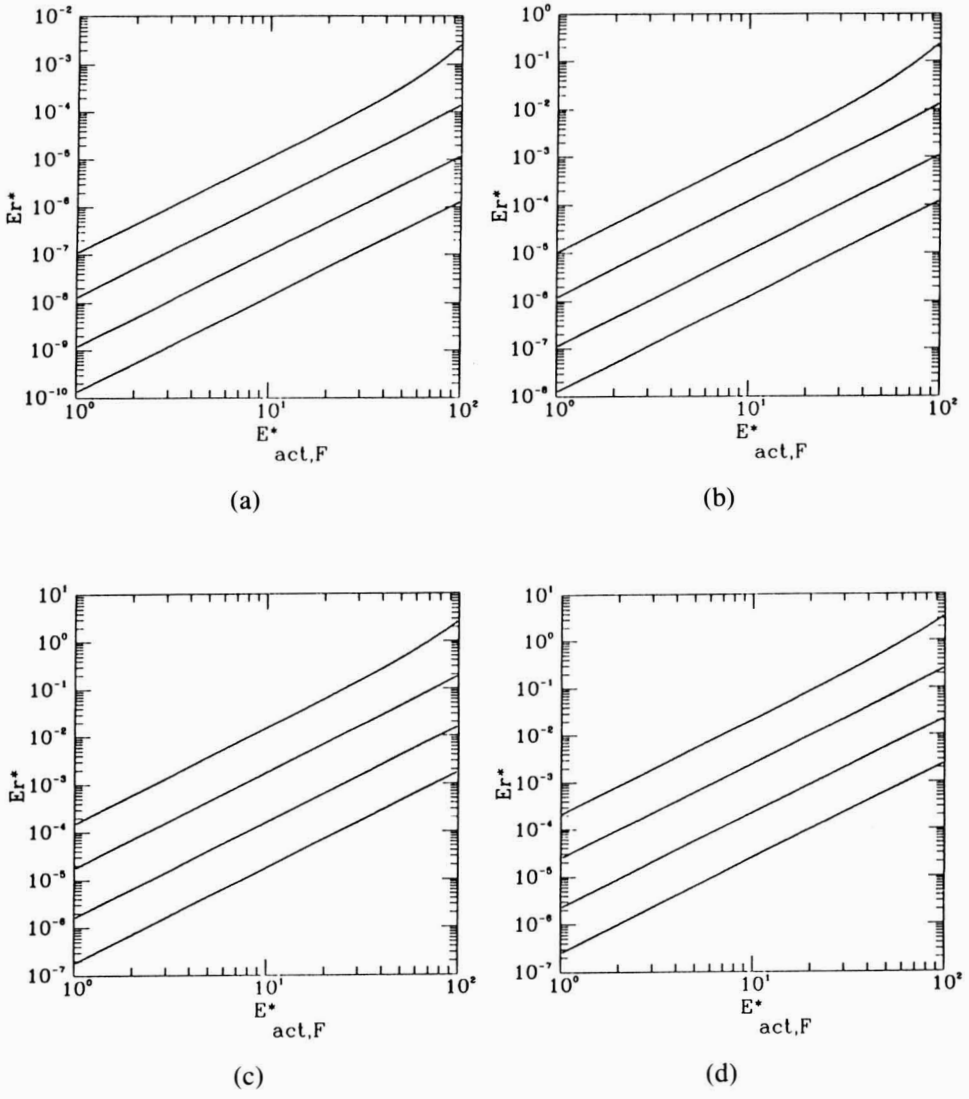

FIG. 1. LOGARITHMIC PLOT OF Er* AS A FUNCTION OF E_{act,F^*} FOR (a) $\zeta = 10^{-2}$, (b) $\zeta = 10^{-1}$, (c) $\zeta = 10^{0}$, and (d) $\zeta = 10^{4}$. From top to bottom: $a^* = 0.03$, $a^* = 0.01$, $a^* = 0.003$, and $a^* = 0.001$.

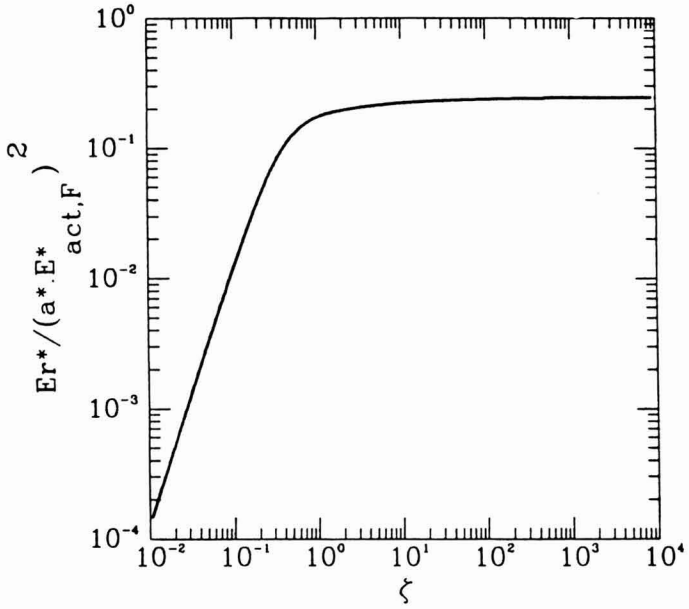

FIG. 2. LOGARITHMIC PLOT OF $Er^*/(a^*.E_{act,F^*})^2$ AS A FUNCTION OF ζ

both values of β_1 and β_2 were approximately equal to 2. Use of this finding in the above equation finally gives

$$\log\left\{\frac{Er^*}{a^{*2}\,.\,E^{*2}_{act,F}}\right\} = Z\{\zeta\} \tag{26}$$

The results of Eq. (26) are depicted in Fig. 2. Inspection of this figure leads one to the conclusion $Er^*/(a^*.E_{act,F}{}^*)^2$ becomes a very weak function of ζ at large ζ [i.e., $Er^*/(a^*.E_{act,F}{}^*)^2 \sim 0.230$]; for very small ζ, one finds that $Er^*/(a^*.E_{act,F}{}^*.\zeta)^2 \sim 1.20$. Taking advantage of these asymptotic behaviors, one can finally propose the following empirical overall relationship between Er^*, a^*, $E^*_{act,F}$, and ζ:

$$\frac{Er^*}{a^{*2}\,.\,E^{*2}_{act,F}} = \frac{0.230\,\zeta^2}{0.192 + \zeta^2} \tag{27}$$

The applicability of the foregoing analysis is emphasized in the practical situation described below.

NUMERICAL EXAMPLE

Consider the case of pasteurized homogenized milk to be stored at 5°C in a large refrigerated chamber as one-quarter, plastic coated paper cartons contain-

erized in 140 cm wide pallet loads. The pallets are laid side by side in the horizontal direction, and top to bottom in the vertical direction so as to form long 140 cm wide independent piles. The refrigerated air contacts each of these piles on the largest two exposed vertical surfaces. The deadband of the temperature on-off controller is such that the temperature fluctuates with an amplitude of 5°C, whereas the regular usage of the chamber leads to a period of 10 min. The physical properties of the milk were obtained from Geankopolis (1983), whereas the activation energy for sensory changes arising from microbial activity in the milk was obtained from Labuza (1982). These flavor changes follow a first order kinetic decay pattern. Assuming that Y is the organoleptic score given to milk (initial score is arbitrarily set to 40, and milk becomes unacceptable after the score drops to 36), the value for the preexponential factor was obtained from a shelf-life vs. temperature plot (Labuza 1982). The shelf-life at the nominal storage temperature is 15 days (Labuza 1982).

The indicator selected was LifeLines™ Freshness Monitor, model 57 (from LifeLines Technologies, Morristown, NJ 07960) which is to be displayed at the outer, plastic-covered surfaces of the pallets directly exposed to the refrigerated air. The physicochemical behavior of this TTI consists on the polymerization of acetylenic molecules which lead to a change of the optical density of the material resulting in the darkening of the indicator (which can be measured with a reflectance probe). The estimated activation energy of this indicator was reported by Wells and Singh (1988a).

Using the above information, the relevant data for the analysis are as follows: $T_m = 278$ K, $L = 0.70$ m, $a(L) = 5$, $\tau = 600$ s, $\rho = 1.03 \times 10^3$ kg.m^{-3}, $C_P = 3.85 \times 10^3$ J.kg^{-1}.K^{-1}, $k = 0.538$ J.m^{-1}.s^{-1}.K^{-1}, $E_{act,F} = 9.12 \times 10^4$ J.mol^{-1}, $k_{o,F} = 1.36 \times 10^{10}$ s^{-1}, $\theta_s = 1.296 \times 10^6$ s, and $E_{act,I} = 8.91 \times 10^4$ J.mol^{-1}. Hence, $\alpha = 1.36 \times 10^{-7}$ m^2.s^{-1}. The dimensionless parameters of interest are found to be $\zeta = 6.02 \times 10^3$, $a^* = 0.0180$, and $E_{act,I}^* \sim E_{act,F}^* = 39.5$. Using Eq. (27), the foregoing value of ζ corresponds to $Er^*/(a^*.E_{act,F}^*)^2 = 0.230$, which in turn leads to $Er^* = 0.116$.

Recalling the definition of Er^* [see Eq. (14)] and the values of $k_{o,F}$ and $E_{act,F}^*$, one obtains that $f_{pred}\{Y\{\theta_s\}\} - f_{true}\{Y\{\theta_s\}\} = 0.0143$. Since the food decays according to a first order pattern, then at the end of the anticipated shelf-life $f_{pred}\{Y\{\theta_s\}\} = \ln\{Y\{O\}/Y_{pred}\{\theta_s\}\}$ and $f_{true}\{Y\{\theta_s\}\} = \ln\{Y\{O\}/Y_{true}\{\theta_s\}\}$. Therefore, one may write $\ln\{Y\{O\}/Y_{pred}\{\theta_s\}\} - \ln\{Y\{O\}/Y_{true}\{\theta_s\}\} = 0.0143$. On the other hand, the quality threshold corresponds to stating that $f_{true}\{Y\{\theta_s\}\} = \ln\{Y\{O\}/Y_{true}\{\theta_s\}\} = \ln\{40/36\} = 0.105$. Using this piece of information, one finds that the relative error involved in the use of the indicator is $[f_{pred}\{Y\{\theta_s\}\} - f_{true}\{Y\{\theta_s\}\}]/f_{true}\{Y\{\theta_s\}\} = 0.0143/0.105 = 13.6\%$, which means that the quality function of the food at the end of the anticipated shelf-life as calculated solely from information provided by the surface-mounted indicator is considerably larger than

the actual value of the quality function. In other words, given the definition of the quality functions as explicit in Eq. (1)–(2), the food would become unacceptable for consumption later than would be predicted by the TTI.

DISCUSSION

The analysis reported above established the theoretical reliability of full-history, time temperature indicators placed on the top of a packaged food item (or on the top of a pile of containerized food items) as shelf-life monitors of the whole food material on the assumption that the classical models for the mechanism of heat transfer and temperature dependence of the food quality and indicator property apply. The food item was assumed to possess slab geometry; this requirement is met by some foods considered individually, and by most foods packed together in large pallets. Similar analyses can be developed for other types of geometry at the expense of more involved expressions for A_r. Furthermore, the pattern of the temperature change might not always be well described by a sine wave (with constant amplitude and period) as assumed. The main goal of the analysis was, however, to provide a quick estimate of the error arising from ignoring the effect of the thermal diffusivity of the food on the temperature profile inside the said food using a reasonable and common type of temperature fluctuation.

It should be emphasized here that the analysis was developed on the assumption that k is a very weak function of temperature (at least in the temperature range of interest) when compared with the corresponding dependence of the kinetic constant associated with the food deterioration (measured by the activation energy), which usually is a good approximation. Although the food may be in a liquid form, no forced convection is expected unless the packages are deliberately shaken in a vigorous way from the outside. On the other hand, although free convection may occur inside the liquid due to temperature gradients, this phenomenon is seldom important because the gradients are not usually large. Even in the worst case corresponding to non-negligible free convection, the equation describing heat transfer inside the fluid in the absence of end effects is of the same form as Eq. (18) (Bird *et al.* 1960), so the analysis reported remains valid in general. The indicator is to be placed on the outside of the packaging material, which has a thermal conductivity different from the food counterpart. However, the conductivities are often of the same order of magnitude (Bird *et al.* 1960), and the thickness of the packaging material is typically one to two orders of magnitude smaller than the thickness of the food material itself. Hence, the contribution of the packaging material to the overall resistance to heat transfer is negligible in most cases.

In the developed application scheme, there is an important underlying assumption; that the effective temperature of the food is equal to the effective temperature of the TTI for a given temperature distribution, which is true when the activation energies of the food and the TTI are equal (Taoukis and Labuza 1989b). Therefore, $E_{act,I}$ was taken as approximately equal to $E_{act,F}$ throughout the analysis, thus paralleling the correct choice of indicator. If the activation energies of the food quality and the indicator property differ by, say, 40 $kJ.mol^{-1}$, then for most types of temperature variation patterns on the surface of the food the error in quality estimation of the surface food layer will be of the order of 15% (Taoukis and Labuza 1989a). On the other hand, the average relative error in estimating the activation energies from experimental data is also ca. 10–20% (Taoukis and Labuza 1989a). Although a tag reliability of 15% is acceptable in most cases (Labuza and Kamman 1983), it should be noted that an extra 15% of error arising from heat transfer limitations within the food (as obtained in the numerical example) will start defeating the purpose of the TTI as an accurate monitor of food quality. Hence, special attention is to be paid to the error arising from small thermal diffusivities in the process of selection or design of a TTI for a given application.

It is interesting to note that although the error associated with ignoring heat resistance effects of the food material depends only on three dimensionless parameters (i.e., ζ, a*, and $E_{act,F}$*), these parameters can be further combined in a trivial way to yield a univariate, known dependence on ζ. Therefore, Fig. 2, or, equivalently, Eq. (27), becomes the most important tool in error estimation. Inspection of Fig. 2 leads one to the conclusion $Er^*/(a^*.E_{act,F}^*)^2$ becomes a very weak function of ζ for ζ larger than, say, 10; in this upper range the bulk of the food remains at T_m at virtually all times, whereas sinusoidal variations occur only at the vicinity of the surface. For $\zeta<0.1$, one finds that there is virtually no difference between the time-dependent temperature profile on the surface and at any other location within the food. Hence, the major effect of ζ on Er* occurs at the intermediate range $0.1<\zeta<10$.

The relation denoted as Eq. (26) breaks down for a* higher than, say, 0.03 and $E_{act,F}$* higher than, say, 100. In general, $10^{-1}<k<2.5\times10^{0}$ $J.m^{-1}.s^{-1}.K^{-1}$ (Geankopolis 1983), $9\times10^{2}<\rho<1.1\times10^{3}$ $kg.m^{-3}$ (Geankopolis 1983), $10^{3}<C_p<4.5\times10^{3}$ $J.kg^{-1}.K^{-1}$ (Geankopolis 1983), $10^{-2}<L<10^{0}$ m, $10^{-1}<a<10^{1}$ K, $10^{2}<\tau<10^{4}$ s, $2.5\times10^{2}<T_m<3.0\times10^{2}$ K, and $2\times10^{3}<E_{act,F}<3.3\times10^{5}$ $J.mol^{-1}$(Taoukis and Labuza 1989a). These values provide working ranges for the dimensionless parameters approximately given by $3.6\times10^{-3}<\zeta<4.9\times10^{5}$, $3.3\times10^{-4}<a^*<4\times10^{-2}$, and $8\times10^{-1}<E_{act,F^*}<1.6\times10^{2}$. Therefore, for most practical applications the values of the dimensionless parameters do not fall above the aforementioned upper limits for a*and E_{act,F^*}, and the simplified analysis keeps its validity.

The reported approach proves particularly useful for refrigerated or frozen foods (especially the emerging extended shelf life foods for which strict temperature control is critical) provided that the necessary kinetic data for the food and the indicator are available. In all cases the response of the TTI is faster than the loss of the quality of the food considered as a whole; hence the error in the prediction will lie on the conservative side. This underprediction of the residual shelf life may, however, be an economic concern since in cases of considerably large values of a*, $E_{act,F}$*, and ζ the TTI will signal the end of the food's shelf-life much earlier than it actually occurs.

It should be emphasized here that with respect to food quality, a number of reactions at the surface will cause rejection of the food and thus the knowledge of the interior temperature variation with time may not be necessary. This would be true for processes that require molecular oxygen to occur such as surface lipid oxidation, nonenzymatic browning, and mold growth. The analysis developed meets its full applicability for degradative reactions which tend to occur uniformly throughout the bulk of the food rather than preferentially at an interface. Examples of these type of reactions include lipase-catalyzed release of free fatty acids, protease-catalyzed breakdown of polypeptides, and growth of anaerobic bacteria.

The above analysis was aimed at developing a numerical method for the *a priori* assessment of the approximate magnitude of the error implicit in ignoring thermal gradients within the food when using surface-mounted TTI's. In order to completely establish reliability, real shelf life data will be required. Examples of these type of analyses have been reported by the Swedish Institute for Food Conservation (SIK) for pallet loads of frozen foods, with a moving freezing/thawing front for application to the I-POINT® tags (from I-Point Biotechnologies A. B., Reston, VA) in the early 1970's. On the other hand, further theoretical research on the effect of different container shapes on the reliability of surface mounted TTI's is warranted because the slab shape is currently limited mostly to dry foods (which very few companies are willing to put TTI's on) and frozen or refrigerated packages. The major features of the method reported are its (1) mechanistic background, (2) general applicability, and (3) numerical simplicity, all of which are likely to make it a useful tool for the food technologists.

NOMENCLATURE

Roman Symbols

a = amplitude of absolute temperature sinusoidal variation (K)
A = cross sectional area of slab (m)
a* = normalized amplitude of absolute temperature sinusoidal variation(--)

a_r = constant (--)
A_r = ratio of amplitude of sine wave at a generic location within the food to the amplitude counterpart at the surface of the food (--)
C_p = isobaric specific heat capacity of food ($J.kg^{-1}.K^{-1}$)
$E_{act,F}$ = activation energy for the food quality parameter ($J.mol^{-1}$)
$E_{act,I}$ = activation energy for the indicator parameter ($J.mol^{-1}$)
E_{act,F^*} = normalized activation energy for the food quality parameter (--)
E_{act,I^*} = normalized activation energy for the indicator parameter (--)
Er^* = normalized error of indicator prediction arising from assuming no heat transfer limitations within the food (--)
f = function of Y only ($mol.m^{-3}.s^{-1}$ for zero order, s^{-1} for first order, $m^3.mol^{-1}.s^{-1}$ for second order, etc.)
F = function of X only ($mol.m^{-3}.s^{-1}$ for zero order, s^{-1} for first order, $m^3.mol^{-1}.s^{-1}$ for second order, etc.)
f_{app} = predicted quality function of the food on the assumption that $E_{act,I} = E_{act,F}$ ($mol.m^{-3}.s^{-1}$ for zero order, s^{-1} for first order, $m^3.mol^{-1}.s^{-1}$ for second order, etc.)
f_{pred} = predicted quality function of the food in the absence of heat transfer limitations ($mol.m^{-3}.s^{-1}$ for zero order, s^{-1} for first order, $m^3.mol^{-1}.s^{-1}$ for second order, etc.)
f_{true} = true quality function of the food in the presence of heat transfer limitations ($mol.m^{-3}.s^{-1}$ for zero order, s^{-1} for first order, $m^3.mol^{-1}.s^{-1}$ for second order, etc.)
G = transfer function in the Laplace domain (--)
i = imaginary unit (--)
I_o = modified zero order Bessel function (--)
k = thermal conductivity of food ($J.m^{-1}s^{-1}.k^{-1}$)
$k_{o,F}$ = preexponential factor for the food quality parameter ($mol.m^{-3}.s^{-1}$ for zero order, s^{-1} for first order, $m^3.mol^{-1}.s^{-1}$ for second order, etc.)
$k_{o,I}$ = preexponential factor for the indicator parameter ($mol.m^{-3}.s^{-1}$ for zero order, s^{-1} for first order, $m^3.mol^{-1}.s^{-1}$ for second order, etc.)
L = half-thickness of the slab (m)
R = universal gas constant ($J.mol^{-1}.K^{-1}$)
s = complex, independent variable in the Laplace domain (s^{-1})
t = time elapsed after food product manufacturing (s)
T = absolute temperature (K)
T_{eff} = effective absolute temperature (K)
T_m = median of absolute temperature sinusoidal variation (K)
T_r = Chébishev polynomial of the first kind
X = suitable property of indicator ($mol.m^{-3}$)
Y = quality parameter of food ($mol.m^{-3}$)

Y_{pred} = predicted quality parameter of the food in the absence of heat transfer limitations ($mol.m^{-3}$)
z = spatial coordinate (m)
z^* = normalized spatial coordinate (--)

Greek symbols

α = thermal diffusivity ($m^2.s^{-1}$)
β_1, β_2 = constants (--)
θ_s = expected shelf life of food (s)
ρ = mass density of food ($kg.m^{-3}$)
τ = period of sinusoidal temperature fluctuation (s)
υ = dummy variable
ς = dummy variable of integration
ξ = dummy variable of integration
Ξ = function of X only (-- for zero order, $mol.m^{-3}$ for first order, $mol.m^{-3}$ for second order, etc.)
Ψ = function of Y only (-- for zero order, $mol.m^{-3}$ for first order, $mol.m^{-3}$ for second order, etc.)
ζ = dimensionless parameter (--)
Z = function of ζ only (--)

Special symbols

L_t = Laplace transform with respect to time (--)
$\forall_x$ = for all values of x

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EUROPEAN HYGIENIC EQUIPMENT DESIGN GROUP FORM (EHEDG)

Following the Symposium of the Society of Dairy Technology in Hythe, Kent, England, April 1984, a number of research laboratories involved in testing the hygienic characteristics of food processing equipment set up the "Committee for the Standardization of methods for testing of the hygienic characteristics of food processing equipment". Currently, a standard method is in use, to test the cleanability (in place) of small plant items such as valves, couplings, pumps, etc.

The same laboratories are involved in advising food companies in designing process lines in such a way that a microbiologically safe product can be produced. A number of important problems are found to reoccur frequently:

(1) Microbiological safety requirements are getting tighter all the time,
(2) There is persistent confusion about expressions (like hygienic, aseptic, sanitary) used by equipment manufacturers and food processors,
(3) There is a general need to improve the hygienic design of food processing equipment.

In addition, national as well as international standardization organizations intend to produce standards on hygienic design of food processing equipment, while existing standards, produced decades ago, often include flaws that may endanger microbiological safety of processed food and hence not always present useful starting points. Available standards as well as those in preparation, to a large extent are not based on evaluation of hygienic characteristics such as cleanability, etc.

Following a number of discussions, it was concluded that there is a need to get specialists together with the tasks as described below:

Objectives

(1) To ensure that food products are processed hygienically and safely.
(2) To provide Standardization Organizations with specialist views on hygienic aspects of equipment design.
(3) To ensure that in the future there will be no confusion whether and under which conditions equipment is microbiologically safe for the processing and packing of food.

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(4) To identify areas where knowledge on hygienic and aseptic design, needed to produce recommendations, is insufficient and to encourage research and development in such areas.

This will be achieved by publication of

(1) Minimum requirements for hygienic and aseptic equipment
(2) Principles of hygienic and aseptic design
(3) Methods, to test whether equipment fulfils the minimum requirements.

To be able to comply with the objectives, the group has been expanded to include representatives from research institutes, equipment manufacturers and the food industry.

Currently, the European Hygienic Equipment Design Group, shortly EHEDG, is formed by:

Research Institutes
Bundesanstalt für Milchforschung, Germany
CFDRA, United Kingdom
INRA, France
TNO, The Netherlands
University of Lund, Sweden
University of Milano, Italy

Equipment Manufacturers
Alfa-Laval
AMRI
APV
Tuchenhagen

Food Industry
H. J. Heinz
Kraft General Food
Nestlé
Unilever

The Group meanwhile has formed the following subgroups:

Test methods Group
Tasks:
To publish current cleanability test method for flow-equipment.
To develop and publish methods for large-size equipment and "open" equipment (such as conveyor belts)

To develop and publish methods to test
—the sterilisability or pasteurisability of equipment
—the penetration of microorganisms.
To develop new methods (e.g. immunochemical) to test the cleanliness of equipment.

Materials Group
Task:
To select materials suitable for hygienic equipment, in particular non-metals, to be used as gaskets, static seals, dynamic (e.g. lip and mechanical) seals, flexible tubing, thermal insulation, diaphragms.

Continuous heat-treatment of food products Group
Task:
To publish guidelines for microbiologically safe continuous heat-treatments, taking into account not only the design of the heat-exchangers, but also the configuration of piping, positions of temperature probes, design and position of flow-diversion valves, and the control system.

Pipe couplings Group
Task:
To design pipe couplings that are easily cleanable in-place, impervious to micro-organisms, easy to install and reliable.

Packing machines Group

Valves Group

Monitoring of plant condition, inspection and maintenance Group

Pump Group

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Page one should contain: the title which should be concise and informative; the complete name(s) of the author(s); affiliation of the author(s); a running title of 40 characters or less; and the name and mail address to whom the correspondence should be sent.

Page two should contain an abstract of not more than 150 words. This abstract should be intelligible by itself.

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Introduction: This should be brief and state the reason for the work in relation to the field. It should indicate what new contribution is made by the work described.

Materials and Methods: Enough information should be provided to allow other investigators to repeat the work. Avoid repeating the details of procedures which have already been published elsewhere.

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In some cases it might be desirable to combine results and discussion sections.

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HASSON, E.P. and LATIES, G.G. 1976. Separation and characterization of potato lipid acylhydrolases. Plant Physiol. *57,* 142–147.

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TABLE 1.
ACTIVITY OF POTATO ACYL-HYDROLASES ON NEUTRAL LIPIDS, GALACTOLIPIDS, AND PHOSPHOLIPIDS

Description of experimental work or explanation of symbols should go below the table proper.

Figures should be listed in order in the text using Arabic numbers. Figure legends should be typed on a separate page. Figures and tables should be intelligible without reference to the text. Authors should indicate where the tables and figures should be placed in the text. Photographs must be supplied as glossy black and white prints. Line diagrams should be drawn with black waterproof ink on white paper or board. The lettering should be of such a size that it is easily legible after reduction. Each diagram and photograph should be clearly labeled on the reverse side with the name(s) or author(s), and title of paper. When not obvious, each photograph and diagram should be labeled on the back to show the top of the photograph or diagram.

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Short notes will be published where the information is deemed sufficiently important to warrant rapid publication. The format for short papers may be similar to that for regular papers but more concisely written. Short notes may be of a less general nature and written principally for specialists in the particular area with which the manuscript is dealing. Manuscripts which do not meet the requirement of importance and necessity for rapid publication will, after notification of the author(s), be treated as regular papers. Regular papers may be very short.

Standard nomenclature as used in the biochemical literature should be followed. Avoid laboratory jargon. If abbreviations or trade names are used, define the material or compound the first time that it is mentioned.

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