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This report contains an examination of the problems faced by the armed forces in attempting to obtain high quality, dehydrated compressed foods as economically as possible.

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Dehydration and Compression of Foods

Prepared by the
Planning Committee for the Workshop on
Dehydration and Compression of Foods
Advisory Board on Military Personnel Supplies
Commission on Engineering and Technical Systems
National Research Council

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NOTICE

The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the Councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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PREFACE

This study was carried out by the Planning Committee* for the Workshop on Dehydration and Compression of Foods to examine the problems faced by the armed forces in attempting to obtain high quality, dehydrated compressed foods as economically as possible. Dehydration and compression of foods offer significant reduction in weight and volume; therefore, they are of significant value to the military in reducing storage and transportation requirements. This is especially important aboard submarines, in space missions, or in military operations requiring that food supplies be carried by the individual.

In order to optimize all factors contributing to the production of high quality dehydrated and compressed foods at reduced cost, members of the Advisory Board on Military Personnel Supplies (ABMPS) and the U.S. Army Natick Research and Development Laboratories concluded that a comprehensive effort was needed to review the state of the art, identify gaps in knowledge, and identify opportunities for obtaining high quality products economically. This workshop on dehydration and compression of foods focused on the current problems relative to quality of end product, cost of production, stability, and utility. It offered a unique opportunity to identify scientific and technological information needed for the synthesis of new ideas in the development of processing techniques of dehydration and compression of foods to yield high quality products at reduced cost of production.

The workshop objectives were to:

- Provide the research community with guidelines to help make research decisions for improving the technology of weight volume reduction and packaging for dried foods.
- Identify cost and quality indices to guide research to meaningful answers for new developments.
- Identify new technologies that may contribute to significant cost reductions and quality improvements.

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*A committee of the Advisory Board on Military Personnel Supplies (ABMPS) of the National Research Council formed to plan and conduct the workshop.

- Identify research and development needs to serve Department of Defense (DOD) logistics requirements for weight- and volume-reduced foods.

Among the areas of knowledge or disciplines represented in the membership of the Planning Committee are the following: processing and economical aspects of dehydration and compression of foods; raw materials for dehydration processes; general food science and technology; food engineering.

The workshop was held at the U.S. Army Natick Research and Development Laboratories, Natick, Massachusetts, on 29 to 30 October 1980, bringing together over 30 participants from industry, academia, and the military to review the status and development of dehydrated compressed foods, to discuss their utilization in the military and civilian markets, and to identify opportunities for reducing the costs of these products.

Funding for this workshop was provided by the Natick Laboratories under the Herbert A. Hollender Workshop Series in Food Engineering and Food Sciences, a program honoring Dr. Hollender for his many contributions to military food programs during his 30 years of service.

The Planning Committee extends special thanks to Dr. Abdul R. Rahman and other members of the Food Engineering Laboratory at Natick for their assistance in planning and conducting this workshop.

SUMMARY

The armed forces has long used dehydrated foods during times of conflict, procuring large amounts and thus enabling such foods to be reasonably cost effective. During peacetime procurement levels are low because these foods are used primarily in training exercises. In addition, small procurements of this type of food for research and development have forced the cost of dehydrated foods, particularly freeze-dried components, well beyond the costs of competing foods preserved by heat or freezing.

Dried compressed foods may be the only source of nutrition for troops during extended periods in the field. While not a subject of this workshop, the nutritional value and safety of dried compressed foods will continue to be evaluated along with other quality factors such as flavor, structure, and color. Ultimately, operational performance requirements are the basis for acceptance of any new technology and these include nutritional value and safety as well as acceptance.

The compression of dried food to reduce volume, as well as transportation and packaging costs has increased the discrepancy between products for civilian use and those suitable only for military procurement. The compression step is usually carried out directly after freeze-drying; these compressed products must be produced for military procurements rather than added on to production runs for civilian use. Air-dried foods have not proved suitable for compression in comparison to freeze-dried products.

The limited needs of the military for compressed dehydrated food during peacetime, coupled with the need to maintain a broad supplier base, has led to small procurements. Since many items are produced seasonally, raw material should be contracted when the seed goes into the ground in order to obtain the variety most suitable for dehydration and compression. Small procurements and the need to maintain a broad supplier base preclude effective crop scheduling.

TOWARD COST-EFFECTIVENESS

Detailed systems cost analyses should be carried out on a regular basis. The procurement, manufacturing, distribution, and use of compressed freeze-dried foods have been, and are being, subjected to systems analysis to ensure a maximum cost-benefit under projected conditions of use. Findings of these reports should be given maximum publicity and incorporated into procurement, funding, and research programs as quickly as possible. These systems analysis studies can help in identifying spin-offs to additional nonmilitary uses for freeze-dried and compressed freeze-dried products to help broaden the marketing base for these products. Industry should develop export markets and identify additional uses in food service.

Research in support of systems analysis findings for new product applications should be a joint effort. Industry funds should be applied to air-drying studies on lower cost components such as fruits, vegetables, and specially formulated products. Efforts are needed to produce suitable compressed dried products from air-dried starting materials.

Raw materials for dehydration and compression must be selected to optimize the performance and acceptability of the reconstituted product. Since specific varieties of fruits and vegetables may not be available when contracts are awarded, frozen starting materials should be used so that the foods can be procured regularly and distributed among several vendors. Freeze-dehydration allows the use of a wide selection of frozen, preprocessed stored foods. However, the low unit cost and high water content of most fruits and vegetables make freeze-drying an expensive method for water removal. There may be a need, moreover, for a change in policy to allow procurement to start with the planting of the seed of special varieties. Frozen starting materials may be difficult to air dry to a quality product.

Research and development programs are needed to allow air dehydration or other relatively new low-cost technologies for water removal to be substituted for freeze-drying. For example, one of these new techniques is microwave-assisted heat transfer, which appears to be most promising for reducing the cost of freeze-drying and improving the efficiency of compression. Preliminary studies indicate that drying times can be reduced significantly, perhaps to four hours, if microwave energy is applied at the start and in the low-moisture portion of the drying cycle. Microwaves have also been used to heat partially dried food prior to compression to facilitate moisture distribution before compression and after compression to hasten finish-drying. Large-scale applications of microwave energy may require strategic planning since units are costly.

Packaging appears to be adequate for the protection of dried compressed foods. Strategic reserves of certain seasonal food materials suitable for dehydration and compression, in dehydrated or dehydrated and compressed form, can be maintained at three levels. Military purchase of frozen foods destined for dehydration and compression can be maintained at a predetermined level. These stocks can be rotated through issue as frozen foods. A second level of inventory can be maintained as freeze-dried components, noncompressed, which can be rotated through civilian products or converted to compressed form. A third inventory would be maintained in the compressed dried form. All stored items, full, part moisture or dried, would be stored below -18°C (0°F) until issued to ensure maximum shelf life upon issue.

Continued basic research is needed to help predict the shelf life remaining in dehydrated compressed foods stored at room or elevated temperatures. Since military storage requirements are far more stringent than civilian, this work should be supported by DOD funds.

New research findings indicate the potential for early detection of chemical precursors of deterioration. As more knowledge is developed on pathways for flavor, color, and structure changes as a function of temperature, composition, water activity, and packaging environment, the significance of selected precursors, their detection, and the measurement of their concentration will increase. This knowledge will speed developments obviating storage deterioration by reducing the need for lengthy shelf life testing.

RECOMMENDATIONS

- Research should be carried out on the structural and chemical composition of vegetables, fruits, meats, and other food items that are being used or considered for the dehydrated and compressed food market with a view toward identifying the factors that contribute to a rehydrated product of optimal quality as to flavor, structure, color, and storage stability.
- Research should be carried out to determine which varieties of vegetables, fruits, and other food items are optimal for the dehydrated and compressed food market, including research on the relationship between maturity (sugar and starch content) and quality (particularly flavor).
- Sulfiting should be eliminated for dehydrated and compressed vegetables where results indicate little or no improvement in storage life; however, research should be carried out on pretreatments and additives that improve product quality and increase shelf life.
- Systems analysis research on costs should be carried out on a continuing basis to determine which drying techniques are most cost-effective and consistently produce high quality products.
- Research should be carried out on the structural and chemical composition of meats, fruits, and vegetables to determine the least costly quality that will produce an acceptable dehydrated and compressed item.
- Research should be carried out to determine the optimum preparation and processing, as well as dehydration and compression parameters required for the dehydration and compression of meat, fish, and poultry alone and in combination with other ingredients to attain the desired item.
- Apparatus and methods to substantially speed the plasticizing and compression procedures should be developed through contract effort.
- Research should be carried out on the adaption of air-dried foods to suitable compressed products.

INTRODUCTION

The U.S. Army Natick Research and Development Laboratories continue to conduct an extensive program to improve the quality of food products and develop rations that are suitable for use under varied tactical situations. Present-day tactics dictate mobility, speed, and dispersion for military strategy. To meet these requirements, rations must be light, have minimum volume, and be easily and quickly prepared. The foods in these rations must also be stable, provide adequate nutrition, and be acceptable to the users. Part of the current research and development in subsistence at the Natick Laboratories is focused on weight and volume reduction of foods.

During World War II, dehydrated foods were used overseas extensively as part of Army rations. However, acceptance of the products was poor. The process had been given little serious attention and was used only as an emergency measure. Since the end of World War II, however, advances in food research, coupled with earlier research, have given impetus to a better understanding of the science of dehydration of foods. This has led to the development of products good enough to be introduced into the commercial market.

In view of the progress in this area, and present thinking with regard to subsistence supply, the armed forces is interested in adopting, as quickly as possible, new technical findings in dehydrated foods. Dehydrated foods have great logistical advantages and definite application to the concepts of warfare now being defined. Recently, dehydrated and compressed foods have become essential for the anticipated long missions of nuclear submarines, which have limited food storage capacity. Nutritional and safety aspects have proven satisfactory under operation conditions.

During the past 20 years, the effects of a large number of process variables on the quality of the finished product have been evaluated. These include varietal characteristics, blanching, time and temperature of treatment, sulfiting and other additives, freezing conditions, freeze-drying conditions, other dehydration techniques, compression techniques, compression, force, dwell time, plasticization, and finish-drying methods. Many successful food items were developed by the military. Some acceptable dehydrated and compressed items are peas, green beans, spinach, mixed vegetables, carrots, apples, and blueberries. Dehydrated compressed salad items, such as cole slaw, were also developed. Meat items such as diced chicken, beef and pork, were also developed but require further work.

Because highly successful dehydrated and compressed foods are costly, the military is especially emphasizing research and development to find methods to significantly reduce the production cost of such items. For example, a significant improvement in the freeze-drying and compression of fruits and vegetables is possible when partially freeze-dried foods are "plasticized" by heating with microwaves, thereby saving about 60 percent of the freeze-drying time and a significant amount of energy. In addition, recent studies have indicated that the sulfiting step may not be needed to prevent degradation of dehydrated compressed vegetables.

This report covers the major approaches identified for further research to improve technology for: (1) Cost Reduction; (2) Raw Materials and Product Preparation; (3) Shelf Life. It was prepared by the members of the Planning Committee who developed the conclusions and recommendations from the presentations and discussions of each session of the workshop as well as from information obtained after the meeting.

COST REDUCTION APPROACHES

A viable dehydration and compression capability in the U.S. food industry would be of unquestioned value to the armed forces. The advantages offered by reductions in the weight and volume of food items, long-term shelf life without refrigeration, and ease of preparation, combined with high quality end products when rehydrated, justify the use of dehydrated and compressed foods for a variety of military missions.

Currently, detailed systems cost analyses are being carried out on the dehydration and compression technology as a whole to provide accurate, timely information on the costs of each operation from raw material preparation to compression and packaging. While detailed figures are not available at this time for many missions, the advantages of compressed-dried foods are so great that cost is only a minor consideration. However, reductions in the present costs would make it possible for the armed services to benefit from the advantages offered by dehydration and compression in a number of other situations. Lower costs would make it advantageous to use dehydrated and compressed foods for garrison feeding abroad and within the United States, particularly when such factors as shipping costs, storage costs, and preparation costs (manpower, equipment, and associated costs) are introduced into the economic equation. An expansion in the military market for dehydrated and compressed foods would stimulate research, driving down the costs still further. If the costs were reduced sufficiently to make dehydrated and compressed foods more competitive in the civilian sector, the size of the market would expand enormously and the technology and the development of a sizable dehydrated and compressed food industry--of great benefit to both the civilian and military sectors--would very likely advance significantly. A large civilian market would guarantee a reliable, varied, competitively priced source of dehydrated and compressed foods for the armed forces.

In the usual competition for budget dollars in the military sector, the funds available for research and development in the area of dehydration and compression have been very limited. The civilian sector has not seen sufficient promise in the development of a commercial market, except in very specialized applications, to justify the diversion of research and development funds from areas with greater and more immediate potential. Research and development efforts to produce higher quality compressed-dried foods probably will need continuing military support in the near term.

DRYING

Military and civilian effort over the past decade has focused on all steps of the freeze-dehydration and compression process. However, the freeze-drying step is by far the costliest part of the process since water must be sublimed at low temperatures and high vacuums.

Opportunities to identify cost-reducing techniques can be found during raw material selection, preparation, and pretreatment. However, the most significant opportunities for cost reduction are:

- Partial drying prior to freeze-drying using more economical techniques for water removal while retaining equivalent product quality.
- Developing methods yielding controllable and uniformly distributed levels of moisture prior to compression.
- Removing moisture prior to freezing or freeze-drying by minimum cost methods such as convection or conduction drying at atmospheric pressure.
- Modifying the freeze-drying method so that the initial end point will leave enough water in the product to allow successful compression.
- Ensuring that water is evenly distributed throughout the pieces prior to compression.

Research is needed on these approaches as well as on the transfer of laboratory findings to commercial practice for specific products.

Of all the dehydration methods that have been found practical on a commercial scale to date (air-drying, vacuum-drying, freeze-drying, puff-drying), the one that has the least detrimental effect on quality, in most instances, is freeze-drying. Freeze-drying has proven to be a superior method of dehydration for most of the commonly used food items including green beans and other beans, peas, carrots, spinach, potatoes, beets, turnips, asparagus, parsnips, green and red peppers, okra, chives, corn, mushrooms, cottage cheese, coffee, cherries, blueberries, strawberries, and a variety of meat, poultry, and fish products. Some notable exceptions are milk, some fruits, and salad vegetables such as cucumbers, tomatoes, lettuce, cabbage, and celery.

The main disadvantage of freeze-drying has been its cost. With the cost of dehydrated and compressed foods now at the point where a small drop in price can produce a sizable increase in the market potential, considerable attention is being given to hybrid schemes that take advantage of the positive effect of freeze-drying on the cellular structure of food but reduce the cost of the process by removing some of the moisture before freezing or freeze-drying. Each of the variety of such schemes raises questions and problems that must be resolved by further research and development on a product-by-product basis. Especially important is the effect a particular scheme has on flavor, texture, color, and storage life. All of these factors must be balanced against the saving in cost. Until detailed systems cost analyses are available only broad areas of research for cost reduction can be identified.

PARTIAL DRYING PRIOR TO FREEZE-DRYING

A food can be partially dried before freezing in order to remove all or part of the unbound and loosely bound water (up to 50 percent of the total moisture content). This can be accomplished by the use of (a) air at temperatures under 93.3°C (200°F) to prevent the item from cooking, (b) liquids at temperatures that are high enough to boil out the water and usually result in some cooking of the item (as is done at the start of the sauté freeze-drying process), (c) radiant heating, (d) conduction heating (using heated trays or tumblers), or (e) a combination of these methods. When considering the economics of predrying, attention should be given to cheap sources of heat (areas of the country in which the climate is hot and dry, or areas in which there is geothermal power or cheap supplies of natural gas) and high altitude. It is assumed that civilian markets would be served first with these production capabilities. Raw material costs would be a prime consideration.

A number of techniques used for the complete dehydration of vegetables and fruits for some purposes (for example, dry soup and gravy mixes and dry snack mixes) can also be used for the partial drying of vegetables, fruits, meats, and seafood that are to be freeze-dried and compressed. Such techniques include the following, either singly or in combination: (a) convection drying, (b) conduction heat drying, and (c) radiant heat drying. If any of the food items to be processed are wet as a result of washing, precooking, or any other pretreatment, a significant amount of energy can be saved by first centrifuging, shaking, blowing air through, or pressing the items to remove the excess liquid. Pressing can also be used to remove some of the unbound moisture in items such as bean curd and cottage cheese, but the use of this technique is limited since it will turn most foods into mush.

Hot air can be used to partially predry most dehydrated and compressed food items, the degree of prehydration that can be done without degrading the final product varies with each item. Frozen starting materials are less suitable for hot air predrying.

When the amount of predrying would result in a considerable saving in total energy use, it might be economically advantageous to locate processing plants in the arid Southwest where the air is warm and dry enough to use in food-dehydrating equipment without any further heating (Flink, 1977). Where the climate is right, the air for predrying might be heated with solar collectors (Food Engineering, 1978b, 1979a, 1979b).

Processing plants might also be located where cheap supplies of natural gas are available. Using natural gas as a source of heat for convection predrying is particularly advantageous. The products of combustion are clean enough to be used directly (mixed with whatever ambient air is required to produce the desired temperature) and, if the plant is large enough, costs can be cut by first putting the combustion products through a gas turbine to cogenerate electricity or produce process steam.

Coal and oil can also be used as sources of energy for predrying but the products of combustion of these fuels are often too dirty to allow them to come in direct contact with foods. Heat exchangers must be used to transfer the heat from their combustion products to process air. Some of this energy could first be used to take care of process steam requirements or to cogenerate electricity. Any other source of energy could be analyzed, of course, including geothermal energy, wastes, and biomass and other forms of solar energy (Food Engineering, 1978a, 1980; Food Processing, 1980; Robe, 1980; Stinson, 1980; Webster and Robe, 1977).

When conduction or radiation (tumblers, spikes, trays, or any of a variety of conveyor systems) (Levine, 1977) is the preferred source of heat for predrying, the heat can be provided by any of the fuels already mentioned, with or without the associated production of steam and electricity. Further economies might be realized by incorporating any of the many other heat recovery and conservation methods now in use in industry (Griffith et al., 1977; Levine, 1977).

COMPRESSION

The tendency of "fully" freeze-dried food items to fall apart on compression necessitates giving them some plasticity. Moisture appears to be the best plasticizing agent; however, to achieve the long-term storage stability required for many military applications, it is necessary to remove moisture used for plasticizing. Fully air-dried foods have not been found suitable for compression after drying.

If water is added to the dry product, the additional energy and time required for the rehydration and subsequent dehydration increase the cost of the dehydrated and compressed food item, limiting the military market and making dehydrated and compressed foods less attractive to the civilian market.

A lesser degree of dehydration can be used before compression. At the present time, vegetables, fruits, and other food items are being dehydrated to an average moisture content of 4 to 6 percent in order to attain a reasonably low moisture content at the center of each piece and a reasonably uniform moisture content from piece to piece. For optimal compression, however, the average moisture content must be increased to 15 to 20 percent. Considerable energy, time, and cost could be saved if a more controlled and uniform drying technique were developed that would allow the moisture content of a food item to be set at 15 to 20 percent before compression.

Microwave energy can be used to equilibrate food pieces that have a low moisture content at the surface and a high moisture content at the center. The use of microwave energy would make it unnecessary to draw down the average moisture content as much as is now being done prior to compression. Methods are needed to ensure an average moisture content of 15 to 20 percent.

Commercially, the product can be rehydrated with mist, spray, or steam. Mist treatments can result in large variations in moisture content from piece to piece (sometimes more than 3:1) and sizable variations within each piece (sometimes as much as 3:1 unless an inordinate amount of time is allowed for equilibration) and can lead to uneven and sometimes unsatisfactory results (King et al., 1976). Overly wet surfaces can result in discoloration and other forms of degradation.

Attempts have been made to avoid the disadvantages of spraying the food to plasticize it prior to compression by rewetting the food with humid air and steam under atmospheric conditions or in a vacuum chamber. Early results were not encouraging (Rahman et al., 1970; MacKenzie and Luyet, 1969; Pilsworth and Hoge, 1973). The rehydration rate was low, and attempts to increase it by increasing the partial pressure of the water vapor led to the same uneven and unsatisfactory results obtained by spraying.

It was recognized early that a fundamentally better alternative to full freeze-drying and spray rewetting would be a partial or limited freeze-drying that would reduce the moisture content of the food item only to the level desired for compression. If this could be accomplished satisfactorily, it would lower costs and produce more even results, two very important advantages.

There are complications, however. Freeze-drying is not an equilibrium process in which the moisture in a food item remains uniformly distributed as the overall moisture content of the item is lowered. The moisture is locked in a core of ice that gradually shrinks in size, leaving behind a region that is relatively dry (King, 1970). When, in a conventional freeze-drying process, the overall moisture content of a food item drops to the level that is considered optimal for compression, the item usually ends up with a wet unstable core and a dry outer region and will not compress satisfactorily.

Several methods for achieving limited freeze-drying have been explored to date, and some of them show promise. King et al. (1976) set up a freeze-drying apparatus in which they could carefully control the platen temperature and the partial pressure of the water vapor in the chamber during the entire dehydration process, and were able to freeze-dry 1cm cubes of beef so that they had a uniform moisture content of about 10 percent in 12 to 13 hours (as compared with a dehydration time of four hours by conventional freeze-drying and a moisture content of 2.5 percent). Subsequent work has resulted in a reduction of the dehydration time by one third (Zakarian and King, 1978). This approach to limited freeze-drying could be commercially useful, particularly if it were developed further and improved. It has the added advantage of allowing the use of available freeze-drying equipment for both limited and full freeze-drying after relatively minor modifications, making major new capital expenditures unnecessary for units already engaged in freeze-drying.

King et al. (1976) also investigated the use of dessicants to control the water vapor in a freeze-drier, since this might make it possible to eliminate most of the refrigeration and heating required.

Calcium chloride offers an advantage of being inexpensive and readily available. Tests showed that it took approximately 8.5 hours for reliable limited freeze-drying and adequate equilibration, beef ended up with an average moisture content of 9.5 percent and turkey with an average moisture content of 11.0 percent.

The ability of microwave energy to generate heat inside a food item uniquely suits it to limited freeze-drying. An economic analysis performed by Hammond (1967) and subsequently revised by Peltre et al. (1977) clearly demonstrates the economic advantages of microwave-assisted freeze-drying over conventional freeze-drying with radiant heat. A more recent economic analysis by Arsem (1980) shows that costs can be cut further by freeze-drying with a combination of microwave and radiant heating. Arsem has also demonstrated the incorporation of a microwave unit into a conventional freeze-dryer, circumventing the need for large capital expenditures when converting to a hybrid system. The resultant doubling of the throughput makes a hybrid system attractive. Most of the effort in this area supported by the Natick Laboratories, both in-house and at Worcester Polytechnic Institute, centers on such problems as corona discharge, nonuniform heating, impedance mismatch, and applicator efficiency (Peltre et al., 1977). Since solid entrainment may play an important role in microwave freeze-drying, it is important that this phenomenon be thoroughly investigated. Also essential are more basic data of the type developed in university laboratories on dielectric, sorptive, and diffusive properties of frozen and dried foodstuffs. The attractive cost savings possible with microwaves have been an incentive to apply microwave heating commercially as a method for rapidly equilibrating partially freeze-dried foods prior to compression.

A new technique in dehydration and compression processing has been the use of microwave heating in combination with vacuum-drying prior to compression. Rehydration of the final product requires about 20 minutes instead of 10. However, for most shipboard applications, this would be of little consequence. Results from a laboratory simulation in a large microwave oven containing the product in a stoppered flask connected to a vacuum source demonstrated that the moisture content of green beans could be reduced to 14 percent in 45 minutes. The product was directly compressable since it was warm and plasticized. Compression was followed by further vacuum-drying to the desired final moisture. The total dehydration cycle using the vacuum and microwave combination was about one hour. A commercial system has been produced by Gigovac of France. (Ref. A. Rahman, Personal Communication.) This continuous vacuum, microwave-heated dryer is 0.6m (2 ft) in diameter and is 2.7m (9 ft) long. Much more work is needed to evaluate drying time against rehydrated product quality of particular foods to make such rapid drying methods practical. Detailed systems cost analyses are needed to justify large capital outlays.

Compression of partially dried foods by centrifugation could eliminate multiple handling steps currently employed in dehydration. In a prototype study, a standard centrifuge tube was adapted by drilling a hole in its base and adding a false bottom. A stainless steel weight could be added to increase pressure during centrifugation. The final product was found to equal products compressed under 100 psi, which is sufficient for most products.

This technique might be applied commercially by centrifically compressing foods in the can used for shipping. Finish-drying could be completed with the product already in the can. Container filling could be increased as much as 25 percent due to space saved between discs and between the product and the walls of the container. However, flexible packages are more desirable and represent a research need.

Sulfite has long been a challenge to the food dehydration industry. It is not allowed in some European countries and Japan. U.S. industries would like to buy sulfite-free, preblanched products for freeze-drying, but current specifications may require the addition of sulfite. Frozen, blanched, sulfited and nonsulfited green beans were freeze-dried by the limited method, then microwave heated for approximately one minute prior to compression. The flavor was found to be quite similar for both treatments even after storing the products at 37.7°C (100°F) for six months. This demonstrates that foods to be used for freeze-drying and compression may not need prior sulfite treatment; however, additional research is needed.

COMMODITIES

Carrots

Objective measurements of the color of raw carrots are the best indicators of their subsequent quality after dehydration, compression, and rehydration (Hruzek, 1973). Rehydration characteristics are directly related to Gardner Color a and the a/b ratio.

Rehydration rates of freeze-dried and compressed carrots are affected by the size of the pieces; the larger the size, the shorter the shed or block disintegration time and, hence, the rehydration time (Macpherson, 1973). Rehydration times increase with the degree of maturity and the sugar content (Bennet, 1976).

Rushing (1975) found that the optimum conditions for compressing freeze-dried carrots without fragmentation were the following: 5 percent sugar, 7 percent moisture, and a temperature of 32.2°C (90°F).

Curry (1974) found that the rehydration rate for dehydrated carrots increased when the carrots were cooked in salted water prior to dehydration. Taking photomicrographs of the dehydrated carrot tissue with a scanning electron microscope, he noted the presence of sodium chloride crystals and concluded they were responsible for the increased rehydration rate because water has an affinity for crystalline salt. When the salt is not in crystalline form because of the presence of impurities, it has the opposite effect, decreasing the rehydration rate. The rehydration rate was highest when the salt in the cooking water was 1.2 percent by weight (0.2 molar salt solution); this salinity also resulted in a rehydrated product of exceptionally good quality (Burns, 1980).

Wisakowsky (1977), in his work on the optimum moisture (plasticization) level in carrots prior to compression, found that the use of microwave heating produced a more uniform moisture distribution, minimizing the cellular compaction noted by Curry. The quality of the final product was found to be best when the moisture level was 10 to 15 percent after dehydration. Microwave heating for 40 seconds prior to compression, at a compression pressure of 500 psi for 20 seconds, proved best. The compression and rehydration were not affected by the relative sizes of the core and outer wall of the carrots used.

In tests on a number of carrot varieties at Texas A&M University, the Danvers 126 variety was found to be the best for the freeze-dried, compressed food market (Burns, 1980). This variety holds up well in the field before harvest, has a harvest period of almost six weeks, and the final product has a superior quality.

Green Beans

The color and fiber content of raw green beans are the best indicators of their potential quality after dehydration, compression and subsequent rehydration (Burns, 1980). A very green green bean with a lower fiber content gives the best results. Although the fiber around the bean facilitates rehydration, a small amount is sufficient for satisfactory results; if the bean is allowed to overmature even slightly before harvesting, it will develop too much fiber and become unacceptable to the consumer.

Spinach

Tests on various types of spinach (smooth, savoy, and semi-savoy) have indicated no discernible change in quality after freeze-drying, compression, and subsequent rehydration (Burns, 1980). A trained taste panel was unable to detect any differences in flavor between the final product and samples of the original that had been cooked without being processed.

Cabbage

Cabbage is one of the few vegetables that does not freeze-dry well. Freeze-drying increases the intercellular spacing, resulting in the absorption of so much water during rehydration that it leaves the cabbage with a mushy texture (Haralampu et al., 1976).

Celery

Celery can be dehydrated best by pretreating with glycerin and air-drying. Because of the high moisture content, the tissue is disrupted by the freezing process leaving crevices that fill with water during rehydration. The result is a mushy texture. Air-drying produces a somewhat better product. Rahman found that air-dried celery could be improved significantly with the use of a water-displacing agent (glycerol, a polyglycerol, or gum, for instance) prior to the air-drying step (Food Processing, 1976).

Celery treated with gums, particularly locust bean gum, has a somewhat better flavor than celery that has been treated with glycerol or various polyglycerols (triglycerol, hexaglycerol, and decaglycerol).

Beef, Pork, Poultry, and Seafood

Freeze-drying is the best process found so far for dehydrating beef, pork, poultry, fish, and shrimp. Air-dried or vacuum-dried animal products do not rehydrate satisfactorily. Freeze-dried, the quality of the rehydrated product is very close to that of the original and, if desired, the item can be compressed after freeze-drying without significantly diminishing the quality of the final product.

It is possible to freeze-dry (and compress) beef, pork, poultry, and seafood in a variety of forms.

High quality cuts of beef and pork can be freeze-dried (and compressed) when they are sliced, cut in chunks for stews and other dishes, or ground for meatballs, patties, or sauces. They can be freeze-dried (and compressed) raw or after they have been cooked, but meatballs and patties require the use of binders if they are cooked first (see "Ground Meat" below). Poorer quality slices and chunks that contain gristle and connective tissue cannot be dehydrated satisfactorily by any method because the gristle and connective tissue become as hard as bone particles and do not rehydrate. These parts of a carcass can be used, however, if they are flaked or cut into small chunks and "restructured" before they are freeze-dried (see "Restructured Meat Products" below).

Poultry (raw or cooked) rehydrates very satisfactorily after it has been freeze-dried (with or without compression). The armed services usually prefer to use raw chicken that has been deboned and diced before freeze-drying.

Fish that has been filleted (raw or cooked) rehydrates very satisfactorily after it has been freeze-dried (with or without compression). Shrimp (raw or cooked) can be processed whole.

Ground Meat

Ground beef in the form of meatballs and patties and ground pork in the form of patties and sausage links can be freeze-dried either raw or after cooking with equally good end results. If ground meat is cooked before being freeze-dried, it is necessary to use binders so that the pieces of meat hold together during the rehydration stage. Binders made from carbohydrates, proteins, and gums (alone or in combination) form matrices that keep the shape of the item intact without blocking the penetration of water.

Formulations and methods of preparation set down for the armed services (U.S. Army Natick Research and Development Laboratories, 1967, 1969) specify the use of pregelatinized corn meal as a binder for ground beef and ground pork that is to be deep fried before freeze-drying and compression. On rehydration with the correct amount of water, the end product has a very satisfactory flavor, texture, color, and shelf life. This product will overrehydrate if there is an excess of water.

Freeze-dried ground beef is now being produced in West Germany on a limited commercial basis with no major problems in its production and utilization so far (Judge et al., 1981). Cost analysis by Judge et al. show differences of 5¢/kg (12¢/lb) between the delivered costs of freeze-dried (unrefrigerated) and fresh (refrigerated) ground sausage meat when transported over long distances, and differences of 2 to 4¢/kg (5 to 10¢/lb) between the delivered costs of freeze-dried (unrefrigerated) and frozen (refrigerated) ground sausage meat when transported over long distances, but these calculations are based on assumptions of capital costs and interest rates that are subject to change.

Restructured Meat Products

The poorer quality portions of a beef or pork carcass that contain gristle and connective tissue can be used for freeze-dried and compressed products if the meat is first cut into very small chunks or flaked and then "restructured." When this is done, the gristle and connective tissue are finely dispersed so the consumer does not notice that they have not rehydrated.

There are other problems, however. Restructured meat tends to fracture or shatter easily after dehydration, indicating that additional work is needed on binders and processing procedures. The presence of fat also causes difficulties; the higher the fat content, the greater the likelihood that fat "smearing" will inhibit rehydration.

There continues to be an excellent opportunity for research on air-drying and other non-freeze-drying methods for the production of compressed animal products. The use of reformed meat, partially or fully dried by means other than freeze-drying and then formulated to allow compression and quality rehydration, should be studied.

RAW MATERIALS AND PRODUCT PREPARATION

The type of raw material selected will have some effect on the procedures used for water removal and compression. Structural, chemical, and composition differences will add their individual unique requirements. Because of their high sugar content, fruits present technical challenges that vegetables do not. Fat content and fiber orientation of meats will influence dehydration and the success of compression.

The most appropriate methods for water removal--freeze-drying, air-drying, or other methods or combinations--have not been resolved. Finished product performance and acceptance exert the greatest influence on which raw material and preparation sequence is used. Although economics is also very important, if performance and acceptance are achieved and a definite military or consumer need demonstrated, economic issues can be resolved in favor of product quality and performance as measured under actual operational conditions.

Frozen fruits and vegetables as starting materials for dehydrated and compressed foods can be selected from existing inventories of frozen commodities or from contracted crops that would be "tailored" specifically for freeze-dried and compressed products. Both sources have been used for the preparation of small quantities for the development stage. Frozen fruits and vegetables are generally available in bulk individually quick-frozen form at a reasonable cost. Availability and price, along with the qualities of the fresh form can be very significant advantages if not outweighed by limitations of commercial style or form, level of blanching, variety, and absence of sulfite treatment.

Tailored raw materials can be used if one or more of the following constraints are met:

- The higher cost is justified by superior quality and performance.
- A reliable source of supply exists.
- The "new" variety has other uses.
- New or modified manufacturing operations are minimal.
- The market size remains significant.

Freezing is used to ensure a supply of starting material because of:

- Seasonality,
- Perishability,
- Geographic location,
- Production schedules, and
- Capital investment needed to prepare raw ingredients.

Procurement methods may not allow sufficient lead time to obtain tailored seasonal plant products. Thus, even if research identifies a highly desirable variety it may not be used. Nonseasonal items are more susceptible to optimization by tailored procurement. Tailored nonseasonal raw materials can be purchased on a more rational cost-benefit basis throughout the year.

Dehydration, compression, and subsequent reconstitution of a food item cannot be expected to improve its flavor, color, or texture. It must possess acceptable characteristics at the start. Some varieties of vegetables and fruits retain their flavor, color, and texture better than others during dehydration, compression, and reconstitution. The varieties of vegetables and fruits now being grown for the frozen food market are, unfortunately, not always the best varieties for freeze-drying. If they were, it would simplify the development of the market potential for freeze-dried and compressed foods. The size of the market at the present time does not justify an investment by a dehydration-compression company in costly varietal development and testing, and in preparation and freezing equipment that would remain idle during a large part of the year. A freezing company might be willing to freeze a special batch of vegetables or fruits for a freeze-drying concern but the order would have to be fairly large. A company that freezes half a million kilograms (a million pounds) of vegetables per day must make special provision to handle an order for the same quantity of a special variety used by a freeze-drying company. In principle it should be possible to work out an arrangement with food-freezing companies for the freezing of optimized varieties of vegetables and fruits given sufficient time. Such a step would not only make it possible to take advantage of the special characteristics of "tailored" varieties of vegetables and fruits (such as moisture, sugar, salt, starch, and fiber content, as well as color, flavor, and texture) but would also make it possible to take advantage of special prefreezing treatments (sulfiting and various types of blanching to control color, flavor, texture, and storage stability).

Some vegetables rehydrate more easily if they are allowed to mature somewhat longer before harvesting but the increase in fiber that results may reduce their acceptability by the consumer.

The trade-offs among the various characteristics of a food item to be dehydrated and compressed must ultimately be determined by the user. The military user may prefer a set of characteristics different from the civilian consumer's. The different types of civilian consumers (institutions, restaurants, survival groups, hikers, campers) may have requirements and preferences that call for different trade-offs among cost, flavor, texture, color, or storage life. In any case, military requirements based on actual operational conditions must be met.

Research is required to obtain fundamental understanding of the relation between rehydrated quality and structural and chemical composition of food items being used or considered for the dehydrated and compressed food market. Structural and chemical composition determines not only the quality of an item (flavor, texture, color) but also the way it dehydrates and compresses. The high fructose and glucose contents of fruits, for example, make dehydration difficult and the product sticky. The development of varieties high in sucrose would simplify the dehydration process and improve the end product.

Size, shape, and uniformity are important factors in the dehydration and compression of vegetables, fruits, meats, and other food items.

Some items (potatoes, onions, meats, apples, strawberries, and mushrooms) that will not dehydrate and rehydrate satisfactorily when processed in large chunks will do so when they have been cut, sliced, diced, flaked, or granulated into thin enough or small enough pieces. A short diffusion path greatly enhances moisture uptake. It is important, however, that the item retain its identity. Some items (peas, beans, kernel corn, cherries, and blueberries) cannot be cut or sliced into small pieces without losing their acceptability. Meat and chicken can be ground or flaked and served in patties, soups, sauces, and rice dishes. Fish can be ground or flaked and served as fish balls. Potatoes can be diced or sliced, flaked for potato chips, or riced for hash-brown potatoes, potato pancakes, and mashed potatoes. Onions can be sliced and served as rings or granulated and served in patties and soups. Carrots can be sliced, diced, "shoe-stringed," and shredded, and green beans can be cut in various ways.

Peas, beans, cherries, and blueberries are being left uncut to retain their identity but must have their skins pierced or slit to enable dehydration at a reasonable rate. Corn kernels have an end sliced off when cut from the cob, but care must be taken in the stripping process. If too deep a cut is made, some kernels will be whole and not dehydrate satisfactorily.

It is important for both the dehydration and compression stage that the size of the pieces in a batch be uniform. A uniform size will enable a more rapid dehydration, better control of the compressed product, and a better rehydrated product.

The opportunity to combine restructuring and reformulation of cut pieces with dehydration methods other than freeze-drying should be exploited. Specially formulated air-dried components may allow satisfactory compression and rehydration without freeze-drying.

SHELF LIFE

PACKAGING

Minimum weight and volume and convenience are key attributes of compressed freeze-dried foods. Appropriate packaging of compressed freeze-dried foods is essential to realize these attributes. To date these packaging needs have been met using rigid metal containers and by adapting existing flexible packaging materials to match the zero transmission properties of rigid metal containers.

While the use of existing packages such as rigid containers guarantees predictable container performance, the use of these packaging systems does not allow the savings of weight and volume of the dried and compressed foods to be realized, particularly when round cans are specified. The use of existing laminates may result in overpackaging or the need for additional internal liners to protect the barrier materials from physical damage.

New packaging systems that meet military requirements for transportation, storage, and handling must be designed specifically for compressed freeze-dried products. The packaging systems must be designed along with the product during its development to obtain maximum savings and optimum performance. As with all products, the effect of oxygen concentration, composition, water activity, and light must be evaluated against quality with storage time and temperature. When requirements for levels of oxygen, water activity, and light are found, appropriate packaging materials can be selected and evaluated against the additional requirements for product protection from transportation, handling, and storage damage.

Two areas of research have been identified. The first is the need for improved shelf life prediction methods. Analytical methods that can be correlated with flavor panel analysis are required since flavor is a critical quality factor.

Second, analytical methods are needed that can be used to predict shelf life as a function of temperature, time, water activity, and oxygen concentration using a minimum number of storage test conditions. Many foods undergo an induction period when flavor changes little progressing to a rapid loss or change in flavor analogous to lipid oxidation in which antioxidants are consumed after the induction period.

Compressed freeze-dried foods are similar to other military rations in that they are often designed for a specific operational use. Long storage life is highly desirable. Often large quantities of rations must be available on short notice. Since the industrial manufacturing capabilities and certain seasonal raw materials may not be available in time of need, ongoing research is required to find optimum methods for strategic product acquisition and storage. An item-by-item systems analysis can identify minimum cost strategies for strategic stockpiling of frozen raw materials, freeze-dried products or compressed freeze-dried products ready for issue. The availability of processing facilities should also be studied since freeze-dryer, vacuum-driers, and microwave heating equipment represents a costly capital investment which cannot be purchased off the shelf with a short delivery time.

Storage conditions for strategic stockpiles of frozen or freeze-dried materials must be optimized to ensure maximum food quality at minimum cost. Storage at -18°C (0°F) or below should be considered in a systems analysis for both frozen and freeze-dried stockpiled materials. Moisture levels (10 to 15 percent) for compression can be maintained at -18°C (0°F), for example. It may be possible to achieve moisture equalization during storage.

Packaging of dehydrated food is necessary to extend shelf life of the product after moisture removal and to prevent mechanical damage. The design of the package must ensure optimum levels of water activity and oxygen independently of the exterior storage environment. It must also provide protection from light, and act as a barrier to micro-organism, insect, and animal infestations even during abusive storage conditions. In addition to extending shelf life, the package must facilitate the transportation, distribution and use of the product, whether it be for civilian or military consumption. The consumers' decision to use dehydrated products is based on cost and quality. Military use is based on operational requirements. These requirements must be satisfied at minimum cost.

Specifications for the production of dehydrated components of military rations reflect operational needs and cost. For example, the original military specifications for freeze-dried beef patties allowed a maximum of 14 to 17 percent fat. This was later increased to a maximum of 23 percent fat in the final product when research indicated that freeze-dried beef rehydrated as well at 23 percent fat as at 17 percent. By increasing the range of maximum fat content in the specifications, the military decreased the cost of the product with little sacrifice in operational performance. Of course, a higher fat content means less protein is available in a given weight of ration.

Packaging specifications must be based on operational needs for the product and low oxygen levels in the meal, ready-to-eat fruit bars. While contractors thought that low oxygen concentrations could be achieved without an inner polyethylene bag, military specifications require this more expensive additional package. This example is included to point out the continuing need for packaging research in support of freeze dehydrated and compressed products. Minimum costs and maximum operational performance can only be achieved by a periodic review of operational needs and of available new packaging materials and systems.

STORAGE

To ensure maximum storage stability, processing procedures no longer under the military's surveillance and control should be spelled out in the product specifications. This would include specifying the proper handling of raw material. The more a product is handled, the greater the potential for decrease in quality in terms of flavor, texture, nutrition, and functionality of the end product. Mishandling of raw materials can lead to unacceptable products after processing. If raw meat or poultry is mishandled, the fat begins to oxidize. Although the oxidation is organoleptically undetectable in the raw product, the mishandled food becomes rancid after freeze-drying.

Certain materials packaged together in the dry state are not compatible when stored at slightly elevated oxygen levels. For example, the deterioration of military long-range patrol spaghetti and chili rations has been linked to high levels of tomato paste. The freeze-dried tomato paste and other dry ingredients maintain their quality longer when stored individually than when mixed.

Another example of the problem of stability of dry blends is demonstrated by a complete pancake mix which included eggs, milk, and shortening. The complete mix, with regular flour, is quite stable. Buckwheat pancake mix without shortening was also quite stable. However, when shortening was added to the buckwheat mix to make it complete, it rapidly became rancid. This demonstrates the need for all dry materials to be mixed and tested for compatibility and shelf life before any new combination can be successfully marketed.

Because the needs of the commercial marketplace are entirely different than those of the military, there is a need for research on the effect of storage of frozen foods to be used for dehydrated and compressed products. The formulation, preparation, and packaging of commercial frozen food is based on a desired shelf life of 18 months at -18°C (0°F). This is adequate for a seasonal supply of raw materials. At a commercial storage temperature of -23°C (-10°F), seasonal products have a shelf life of several years. This effort should be undertaken with military support.

The military should study the need for a stockpile of frozen foods since price may depend on the shelf life and storage period of the food. Factors that can adversely affect the stability of food in cold storage are mishandling of the raw products and residual enzyme activity from inadequate blanching or microbial sources. The delay between harvesting, and blanching and freezing can determine the storage life. Slight variations in handling and processing times could result in dramatic differences in quality over the longer storage periods necessary for military stockpiles.

Storage temperature is also very crucial for extended storage of frozen foods. Cod stored at -8°C (18°F) reaches a just noticeable difference (JND) in flavor in approximately seven weeks, whereas cod handled in a similar manner and stored at -30°C (-22°F), as in the large European cold stores, will reach the JND in seven years. Products with high concentrations of electroyles such as salted butter, salami, and bacon have a shorter shelf life during frozen storage than refrigerated storage (Olson, 1971). The cost of energy for storage of a military stockpile can determine to a great extent whether the food will be stored frozen or compressed and dehydrated.

The use of microwave-assisted equilibration during the dehydration and compression process can provide a more satisfactory storage-stable product. Depending on the type of equipment used, 10 to 14 hours are usually needed for the dehydration of green beans. This time could be significantly reduced if the drying process were stopped when the product reached a moisture content of 10 to 30 percent in approximately 5 1/2 hours. Compression could take place at this moisture level if a 40- to 45-second microwave treatment is used to cause the moisture to diffuse from the center of the product to the relatively dry exterior, thus plasticizing the food. Compression and further drying by other techniques such as vacuum-drying would complete the process. The availability of costly microwave and vacuum equipment must be assessed.

Theoretically, compressed foods are not exposed to as much oxygen as noncompressed foods in containers. The physical action of compression discharges oxygen from within and between the cells of the product. The resulting high-density product is less sensitive to the residual headspace gas. For example, the flavor of sulfited and nonsulfited freeze-dried compressed carrots and peas was found to be quite similar even after storage at 37.8°C (100°F) for six months. All of these products were packaged in flexible pouches under a vacuum of 101.1cm (28 in.) of mercury. While the use of an aluminum foil laminate in the pouch is believed to be equivalent to packaging in a full steel can with limited headspace, the military operational requirements for shipping, storage, and handling increase failure rates for existing flexible materials than steel cans.

FOOD KINETICS

A critical factor which does not receive much attention in shelf life studies is the lag phase. High-temperature/short-time accelerated storage studies do not provide information on actual storage conditions due to the absence of an induction or lag phase. Most methods of analysis are not sensitive enough to detect chemical changes during the induction period.

Recent developments in inverse gas chromatography (IGC) may help detect the small changes taking place during the induction or lag phase. The degradation by hydrolysis of a mixture of lactose and aspirin was studied as a model. The rate of hydrolysis of this complex at low temperatures was found to be related to the moisture content since the hydrolytic action dominates. At high temperatures, the kinetics change drastically and the storage stability is less dependent on moisture content. This phenomenon has been well known by those who market compounds such as aspirin in pill form, but previously there was not a clear explanation for it. By using the technique of IGC, a reasonable answer was found.

The basic principle of IGC is that a carrier gas is passed through a stationary phase (food). It is the reaction of the stationary phase that is of interest in this type of chromatography instead of the carrier gas. The system was applied to the early low-moisture phase of water absorption by collagen which is present in most meat. By measuring the hydrogen bonding sites of collagen as a function of concentration, workers were able to form an alternative definition of bound water (Coelho et al., 1979).

Hydrogen bonding as a thermodynamic parameter of a dehydrated food system is highly concentration dependent--that is, the lower the moisture content, the more difficult it is to remove the water from the sample. By using IGC, the energy requirement for removal of water at low moisture levels can be measured.

This technique could be used to study oxidation of food systems by using a continuous stream of moist carrier gas with a specific low oxygen concentration. With time, the response would be proportional to oxygen content. Changes in oxidation could be measured in the presence of light or an antioxidant. The oxygen sorption relation could be used to study the factors related to the lag phase in color changes in nonenzymatic browning or in changes in peroxide values.

IGC could possibly be used to create drying curves for various foods by passing a carrier gas of known moisture through a food at a given temperature. Changes in the thermal conductivity of the outgoing gas over time could be measured, thus giving an estimation of the drying properties of the food. Changes in the shape and size of the food particles would allow a study of the relationship between physical factors and drying rates.

With the increased knowledge of the kinetics of changes in low-moisture foods during storage, it is possible to simulate such changes by using sets of descriptive equations or models. Kinetic models are based on the process rate, which describes quality changes by the general equation:

$$-dC/dt = f\ (E_1 \ldots E_N,\ F_1 \ldots F_N)$$

(Saguy and Karel, 1980)

In dealing with the problem of predicting the shelf life of a food, certain definitions are needed. The first definition needed is that of the quality of the food or F. Deriving this definition is very often the basic problem in dealing with shelf life. Depending on the food, its desired use, and the inspector, quality will always be a variable term. A standard index of quality must be agreed upon. This index may be the result of an organoleptic test, oxygen content, peroxide value, moisture content, or another characteristic; but without a common index, the mathematics of a kinetic study is meaningless.

The quality of food is known to be a function of the environment surrounding the food inside the package or E. This may be oxygen pressure, water vapor pressure, or presence of sulfur dioxide in the air. It also depends on the initial quality of the food and time.

This interior environment is in a constant state of flux, depending on the oxygen content of the initial packaging. The food is constantly absorbing and emitting gases. This dynamic system is also dependent on the environment outside the package, barrier properties of the package, and time.

The barrier properties, which are very important in determining the shelf life of a low-moisture food, are at times very dependent on the internal and external conditions. For example, cellophane at high humidities will readily transmit oxygen, but if kept at low humidities on both sides, it is a very good oxygen barrier. Thus, optimum packaging lies somewhere between the rigid round steel can and perhaps the cellophane wrapper used to package dry split pea and bean soup mixes for the retail consumer. At this point, storage and operational needs must be clearly stated so that minimum-cost packaging systems can be tailored to provide a minimum-cost operational product.

NEEDS, OPPORTUNITIES, AND CHALLENGES

A broadly stated objective of the workshop was to identify research guidelines and opportunities for obtaining high-quality, cost-effective, shelf-stable foods offering weight and volume reduction for both military and possible civilian applications. In attempting to develop civilian markets, it is important to identify and compare military and civilian needs for weightand volume-reduced foods, to identify the critical problems that compressed, dehydrated foods solve and the problems that remain to be solved, and to consider the cost/value relationship of the required technology.

The need for weight- and volume-reduced foods for the combat soldier and, to a lesser extent, for the shipboard sailor is easily documented and understood. Ever since the first two soldiers picked up their spears and began to march in step, weight and volume reduction, shelf life extension, and quality improvement have been basic goals for military subsistence research and development. Today, our peacetime defense capability is based on ever-ready, highly mobile, response forces supported with advanced technology and advanced weapon systems. The logistics problems and space restrictions dictate that the weight and volume of food items be minimized. Dehydration and compression processes have been remarkably responsive to meeting these needs. In addition, dehydrated rations are tolerant to, and remain functional under, extremes of temperature.

The military has taken a leadership role in the development and adaptation of the sophisticated technologies required to produce dehydrated and compressed foods that are highly acceptable, safe, and nutritious. A number of items are being procured, primarily for submarine feeding. Their high cost can be justified by those space-premium applications where no alternatives exist. The majority of our peacetime military personnel are fed by various types of food service operations which are like their civilian counterparts and which are governed by the same economic considerations. The food service's need for reduced weight and volume might be questioned even if the costs were comparable.

The dehydration and compression process, particularly if based on freeze-drying, is a high-capital, low-volume, labor-intensive, costly process. In addition, special packaging is required. Thus, whether the product would ever be competitive with counterpart products or attractive to the bulk of the military or civilian market can be questioned. The cost problem is further aggravated by the military accounting system. There is no single responsibility for gathering all the costs (for instance, military labor) in the entire feeding system, from the point of procurement to the point of preparation and consumption. Dehydration and reduced weight and volume offer potential cost savings in shipping, storage, preparation, and disposal. Studies are now under way to identify and detail costs and savings.

Further implications of the current limited usage of compressed, dehydrated foods are the inability to stock small lots--due to the absence of an adequate civilian production base--to allow diversified evaluation and to procure significantly large quantities quickly in the event of a major mobilization. The high capital costs of dehydration and microwave equipment are a consideration.

At this time, the process has been most successful for vegetables and selected meat items which can be obtained from existing frozen stores.

Technical needs include:

- Improved dehydrated meat pieces.
- Good quality, dehydrated salad vegetables.
- Precooked, quick-cooking beans.
- Dehydrated large pieces of vegetables which rehydrate completely in a reasonable period of time.
- Dehydrated and compressed whole cuts of meats, such as steaks and cutlets.
- Improved packaging to take further advantage of reduced weight and volume.

Technical opportunities include:

- Sautéed freeze-drying for improved stability and flavor.
- Puff-drying for low-cost, quick rehydration, precooked vegetables.
- Improved air-drying.
- Precooking and conditioning to facilitate rehydration.
- Dehydration and compression of larger pieces of vegetables.
- Combined freeze-drying with other methods of drying.
- Formulation of flaked or size-reduced foods, non-freeze-dried into compressable end products.

Technical challenges include:

- Dehydration and compression of fruits and salad vegetables.
- Increased understanding of parameters critical to quality.
- Increased understanding of engineering parameters required to optimize existing processes.
- A breakthrough to reduce the cost of freeze-drying or to develop a low-cost alternative to freeze-drying.

If there is a need, or opportunity, for compressed, dehydrated foods in the civilian sector, it must be based on their logistical advantages and convenience and might entail application of technology to develop items different from the current military items. Perhaps there are opportunities to apply the technology so as to make it economically attractive to distribute certain food items world-wide to compete with locally produced items, or to offer items not available in other localities. Continued research is needed.

Dehydrated vegetables are distributed internationally to industrial remanufacturers, food services, and fast-food operations, and freight costs are a growing and substantial portion of the total cost. Significant savings should result if the volume of these shipments could be reduced, and an already substantial volume of business might be increased. Application of compression technology to larger (bulk) units would be desirable.

Compressed dehydrated items do offer shipping and storage economies. These should be much more readily recognized and quantified by the industrial or food-service user than by the home consumer. Items developed for the mobile combat soldier are not likely to be right for the food service consumer, military or civilian. But the needs and problems of the food-service operator should be surveyed so that appropriate items can be developed for him.

Cost and quality trade-offs must be evaluated for each application. The best quality may not be affordable or necessary for all users. Systems studies of costs underway should resolve these questions.

Industry shares the military's concern for the relatively high cost of dehydration. The military should be assured that the civilian sector continues to work to reduce these costs through process improvement and innovation, as well to develop process alternatives. This research will be driven by the need for specific civilian products, including items for the food service industry and for international markets.

The military must continue to develop the knowledge base through an ongoing research program necessary to meet its particular product objectives. It must share and promote this knowledge base and develop technology with the civilian sector where it can be applied to the solution of problems and meeting of needs of the civilian market segments. Military support must be provided for the research, development, and production of dehydrated, compressed foods filling essential military operational needs.

APPENDIX

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BIOGRAPHICAL SKETCHES

PLANNING COMMITTEE FOR WORKSHOP ON DEHYDRATION AND COMPRESSION OF FOODS

Daniel F. Farkas is Chairman of the Department of Food Science and Human Nutrition, University of Delaware. Prior to this appointment, he was a research chemical engineer and head of the Food Engineering Development Group at the Western Regional Research Center of USDA, Berkeley. He received his B.S., M.S., and Ph.D. in Food Science from the Massachusetts Institute of Technology. Dr. Farkas has served on the faculty of Cornell University. His research has focused on food processing operations and equipment. He is a Registered Professional Chemical Engineer in California.

Dennis R. Heldman earned his B.S. and M.S. degrees in Food Engineering at Ohio State University and a Ph.D. in agricultural engineering at Michigan State University. He authored a textbook entitled Food Process Engineering published by AVI Publishing Company, Westport, Connecticut, in 1975, and coauthored the second edition of the same book which was published in 1981. The book contains a chapter dealing with the subject of food dehydration.

Jack R. Linaberry received his B.S. and M.S. degrees in Chemical Engineering from Bucknell University. He was Research Manager of California Vegetable Concentrates, a Division of General Foods, Modesto, California, prior to becoming Laboratory Manager of the Maxwell House Division of General Foods Corporation, Hoboken, New Jersey.

Hugh W. Symons is Vice President, Research and Technical Services, American Frozen Foods Institute. He was educated at Queens' College, Cambridge (United Kingdom). Mr. Symons served as biologist aboard a whale factory-ship during seven whaling seasons in the Antarctic and South Africa. He was in charge of the Quality Control Department for Birds Eye Foods, Ltd. (U.K.). He is a member of Commission C2 (Food Science and Technology) of the International Institute of Refrigeration.

WORKSHOP PROGRAM

Workshop on Dehydration and Compression of Foods

29-30 October 1980

U.S. Army Natick Research and Development Laboratories
Natick, Massachusetts

Wednesday, 29 October

Opening Session

Introductory Remarks	Dr. Daniel F. Farkas University of Delaware Chairman, Workshop
Welcome	Col. Robert J. Cuthbertson Commander, Natick Laboratories
Military Needs	Dr. Abner S. Salant Director, Food Engineering Laboratory, Natick Laboratories

Session I: Technical Needs and Opportunities

Chairman: Mr. Jack R. Linaberry
General Foods Corp.--
Introductory Remarks

Panel Members: Mr. Holt "Pete" Andrews,
Thomas J. Lipton, Inc.;
Mr. Donald L. Davies, Swift & Co.;
Dr. Enrique J. Guardia, General Foods Corp.

This session should identify quantitatively cost-quality parameters for military and civilian users. Projections are desired for future demands and types of new products.

Session II: Raw Materials and Product Preparation

Chairman: Mr. Hugh W. Symons
American Frozen Food Institute--
Introductory Remarks

Panel members: Dr. Thomas M. Crawford,
Stokely-Van Camp, Inc.;
Dr. Julius F. Bauerman, H. W. Longacre, Inc.;
Dr. Edward Burns, Texas A&M University;
Mr. Edward Hirschberg, Innovative Foods, Inc.

This session should identify raw materials, preparation, and processing needs to give optimum weight and volume reduction and reconstitution. Animal and vegetable commodities will be considered in addition to problems related to formulated or engineered foods. Also to be considered are factors such as food safety, quality, season, and growing areas.

Adjournment

Dinner Meeting

Presentation: Financial Considerations and Opportunities--
Mr. Jerry Graham
Right-Away Foods Company

New business, venture capital, product development, and technical base requirements in support of increased use of dried and compressed foods will be highlighted.

Thursday, 30 October

Session III: Weight and Volume Reduction Technology

Chairman: Dr. Dennis R. Heldman,
Michigan State University--
Introductory Remarks

Review of recent developments in dehydration technology--Discussion Leader--Dr. C. Judson King, University of California at Berkeley

Mechanical dewatering as an aide for weight and volume reduction for dehydrated foods--Discussion Leader--Dr. John R. Rosenau, University of Massachusetts

Recent applications of microwave technology to food dehydration--Discussion Leader--Dr. Edward Ma, Worcester Polytechnic Institute, Massachusetts

Recent developments in application of the freeze-drying process to food dehydration--Discussion Leader--Mr. Harmon L. Liebman, Eastern Freeze-Dry Corp.

Potential energy conservation measures for food dehydration--Discussion Leader--Dr. John M. Krochta, USDA/SEA, Berkeley, California

Economic considerations in food dehydration--Discussion Leader--Mr. James C. Craig, Jr., Eastern Regional Research Center, USDA

This session should identify new technical developments and research needs. Emphasis is to be placed on cost reduction and energy conservation with simultaneous improvement in product quality. All forms of water removal will be discussed.

Session IV: Packaging, Transportation and Storage

Chairman: Dr. Daniel F. Farkas--
Introductory Remarks

Panel members: Mr. Marvin Byer, Oregon Freeze Dry Foods, Inc.;
Dr. Seymour G. Gilbert, Rutgers University;
Dr. Marcus Karel, Massachusetts Institute of Technology;
Dr. Abdul R. Rahman, NLABS;
Mr. Hugh W. Symons

This session should identify product-package interactions and approaches to reduce packaging, storage, and distribution costs. The effect of product composition and processing methodology on the rate of quality change for various packaging and storage conditions will be covered. The cost-effectiveness of special storage conditions and methods for measuring benefits will be analyzed.

Workshop Summaries

Chairmen of Sessions

Adjournment

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