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REVIEW OF ARMY FOOD RELATED OPERATIONS IN HOT DESERT ENVIRONMENTS

By
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February 1991

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October 1990 - December 1990

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The climate and terrain in the Operation Desert Shield/Storm (ODS) area of operations are typical for a low, hot desert. This hot, dry, windy environment has significant impact on feeding and food management. In order to identify specific issues associated with this type environment a literature review was conducted. The literature review led to several conclusions and recommendations which could be applied immediately to improve the quality and acceptability of food and ensure adequate fluid intake thus ensuring adequate consumption and reducing the probability of heat casualties among ODS personnel.
Strategies to ensure that personnel exercise necessary discipline toward maintaining optimum hydration and nutritional status should be implemented as soon as possible.

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PREFACE

In order to identify specific feeding and food management issues likely to arise in Operation Desert Shield/Storm (ODS), and at the request of the Commanding General, Army Materiel Command, a literature review was conducted. All available literature that in any way addressed hot weather feeding was reviewed between 22 Oct 90 and 6 Nov 90. This effort was in part supported by computerized literature searches making use of Food Science and Technology Abstracts and the U.S. Department of Agriculture Database.

On 7 Nov 90, the results of the literature search were presented at the first meeting of the High Heat Environment Food Quality Task Force. This group used these data as part of the foundation for discussions and to reach conclusions during the course of their meeting.

ACKNOWLEDGMENTS

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EXECUTIVE SUMMARY

Previous military experiences in desert environments indicate that there are peculiarities of feeding and food management at high temperatures that merit further investigation and require special management. The climate and terrain in the Operation Desert Shield/Storm (ODS) area of operations represent classic desert conditions, which must be accounted for in terms of their impact on our ability to feed and hydrate soldiers and subsequently maintain effective combat operations. It is essential that soldiers involved with ODS maintain appropriate levels of nutrition and hydration in order to avoid heat casualties and to perform effectively. In addition, the impact of high-quality food and drink on morale in this extremely hostile environment cannot be overstated.

For the most part, management of hot weather food issues can be accomplished through informed leadership. There are, however, some striking departures from customary procedures and these merit intensive review at all levels. A summary of the most significant conclusions and recommendations derived from the literature review follows:

a. Maintaining proper hydration status is the most critical issue facing individuals operating in desert environments. The normal thirst mechanism will not adequately motivate personnel to maintain proper levels of hydration, particularly when heavy work or battle stress are brought into the formula. It is absolutely essential to provide adequate fluids to personnel, in the form of water or other liquids, and to train and ensure that all personnel consume the quantities of liquid the body requires. Such strategies as cooling or flavoring water, providing adequate rest time for rehydration, strict water discipline, providing adequate, but not excessive, salt, and avoiding foods and optional activities which exacerbate dehydration are needed during desert operations.

b. Nutritional considerations during prolonged exposure to hot weather are slightly different from those expected in temperate climates. Excess protein may have a detrimental effect due to the heat generated during its normal metabolism and the added water requirement associated with the excretion of its metabolites. Generally, desert feeding should focus on complex carbohydrates, with balanced protein and moderate fat. Supplemental items high in carbohydrates and low in protein and fat (e.g., fresh fruit/dried fruit/fruit bars) should be made available to soldiers to help them maintain a proper diet in a desert environment. During periods of extreme heat, individuals tend to lose interest in eating, which results in weight loss. This can have a deleterious effect on performance. Training, highlighting the direct correlation between good nutrition and performance, to ensure adequate food consumption in concert with strategies to encourage consumption, such as scheduling meals during cooler periods of the day, providing at least one hot meal a day, and utilizing heat stable commercial products, should be implemented.

c. Food deteriorates much more rapidly during hot weather. This characteristic has both wholesomeness and quality implications. From the wholesomeness perspective, food should be handled in accordance with good sanitary practice to avoid microbial contamination with subsequent rapid microbial growth leading to food-borne disease. The desert environment mandates emphasis on preventive measures to avoid food-borne disease. From the quality perspective, any measures that will protect food from the heat will contribute to more consumable products. Such strategies as underground storage, use of insulators, use of ventilation, rapid turnover, and avoiding prolonged storage in direct sunlight will maintain quality and encourage consumption.

There is a scarcity of specific information on the effects of high heat on feeding and personnel performance. Further, there is a void in information on product shelf life (e.g., serviceability and acceptability) at elevated temperatures. There is a need to initiate studies in several areas to identify optimum nutrient composition, most desirable products, and best preservation measures for food items toward promoting the individual soldier's combat effectiveness in the desert environment.

1. Introduction.

A review of the literature was conducted to support the High Heat Environment Food Quality Task Force in its mission to evaluate feeding and food management related problems encountered or anticipated in Operation Desert Shield (ODS)[1,2,3].

2. Southwest Asia Area and Climate.

a. The climate of the Middle East has a strong resemblance to that of Yuma, AZ. During July, the hottest part of the year in Saudi Arabia, the following temperatures can be expected:

(1) The mean daily maximum temperature is between 110^{o}F (43^{o}C) and 120^{o}F (49^{o}C), with absolute daily maximum temperatures between 120^{o}F (49^{o}C) and 130^{o}F+ (54^{o}C+), particularly in the open desert.

(2) The mean daily temperature is between 90^{o}F (32^{o}C) and 100^{o}F (38^{o}C), with the mean minimum between 80^{o}F (27^{o}C) to 90^{o}F (32^{o}C).

b. During January, the coolest part of the year, mean temperatures between 50^{o}F (10^{o}C) and 70^{o}F (21^{o}C) can be expected.

c. Rainfall occurs almost entirely in the winter and spring months of January through May. Annual rainfall is 5 to 10 inches. Relative humidity parallels rainfall and is low.

d. Wind is constant during the day and is moderate in strength; about 10 mph.

e. The dominant weather conditions in the ODS area of operations can be characterized as hot, dry and windy with blowing sand and dust.

f. Southwest Asia is only a small part of Asia, but it is two thirds as large as the United States. From south to north, Southwest Asia extends from 12^{o}N to 42^{o}N and if superimposed on North America, it would almost span the distance from the Panama Canal to the Great Lakes. From western Turkey to the eastern border of Iran is approximately 2500 miles, a distance equivalent to that from New York to Seattle[4,5,6].

3. Historical Experience.

a. The following summaries are from documents detailing desert warfare during World War II.

(1) <u>American/British</u>: 1941-1946, North Africa, excerpts from R.E. Johnson's "Feeding Problems - U.S./Canadian Army Ration (D. Ration Trials-Desert Areas)."

(a) Desert environments sometimes impaired appetite. British tank crews became so fatigued that they preferred resting to the trouble of cooking. The gas stoves could not be used at night because of blackouts. Tank crews deprived of adequate rations became exhausted sooner. On the other hand, the German tank crews had hot food brought to them in mobile kitchens. In very hot weather, as in the desert, appetite is disturbed during acclimatization. Cool beverages and ice stimulate the appetite for solid food. Fruit juices were well liked. Sometimes it was possible to change meal hours to cooler parts of the day, such as early in the morning or late at night, leading to increased consumption rates.

(b) Inefficiency and then exhaustion may develop in a few hours from lack of water. In the desert, the whole process up to collapse may take only three to four hours. Men, during work, ad libitum usually drink two thirds the water lost in sweat.

(c) Caloric deficiency produces physical and mental disturbances, which range from disgruntlement and irritability to gross physical deterioration. In the desert, with high work output, such signs and symptoms can occur in two days. Unless officers and men are aware that gross loss of military efficiency and operational fitness can occur from eating too little food, the cause of the loss of efficiency will usually be attributed mistakenly to poor quality in the troops, poor leadership or other factors. With minor degrees of caloric deficiency, besides unusual hunger, which is sometimes absent, physical and other disturbances appear. These are varied and consist of slight depression with some loss of discipline and morale, irritability, disgruntlement, sullenness, and lack of enthusiasm and vigor. Symptomatic recovery from the early effects of caloric deficiency is usually dramatic after sufficient food and drink are consumed. Generally, however, men do not attain their former fitness until they have been on a normal diet and have rested for days or weeks[7].

(2) German: North Africa Feb 1941 - May 1943. The following are summaries from A. Toppe's "Desert Warfare - German Experience in WWII":

(a) It was not the climate alone that caused the heavy losses that were suffered, but the poor food and the hardship during combat combined with the effects of the climate; the troops had in no way been prepared for these circumstances (their diet consisted almost exclusively of canned foods).

(b) No prior lengthy acclimatization should take place since this would waste part of the first year of maximum efficiency; after one year, rotate troops to another theater. Newly arrived units had low fighting power and many losses through sickness. The heat paralyzed the men's willpower; the diseases were probably more a direct result of the diet (bad water, canned food) and hardship than of the heat.

(c) Heavy physical exertion required about the same food intake as at home. Too much meat, especially canned meat, was rejected by the men. Vegetables and fruits were more popular than meat. Too great a meat consumption considerably increased the body's need for water.

(d) Fresh meat is preferable if refrigeration facilities are available. Smoked meat, especially hard sausage which is not too fatty, found a good audience. All sorts of dried fruit proved very satisfactory.

(e) The consumption of concentrated alcoholic beverages should be carefully avoided. The best principle is "no alcohol before sunset."

(f) As wide a variety as possible should be attempted in the menu, as the troops came to dislike foods that were served continually[8].

b. The following are summaries from the U.S. Army Materiel Command Lessons Learned series and other studies describing several pertinent changes in the Meal, Ready-to-Eat (MRE).

(1) A research study was conducted in 1986 on 27 soldiers fed MREs as their only food for a 34-day field exercise and 30 soldiers as controls fed a hot breakfast, hot dinner and an MRE for lunch. The men fed only MREs showed significant weight loss compared with those fed hot meals. (Body weight loss of 5.8% versus 2.6% for control.) According to the Office of The Surgeon General (OTSG), weight loss of over 3% may negatively influence performance. Both groups had normal nutritional status and neither group was dehydrated[9]. However, the group eating only MREs showed significantly less daily intake of calories and nutrients. It was determined that when soldiers are suddenly switched to a prescribed diet, they may not eat enough initially to maintain their weight. Recommendations were made to give more appetizing caloric items and/or increase the portion size in the MRE to encourage intake[10].

(2) During 29 April to 9 May 1988 the fully improved MRE, MRE VIII, was evaluated by the 82nd Airborne Division in exercise Market Square II. The fully improved MRE included: an increase in the portion size of the entree from 5.5 ounces to 8 ounces; nine new entrees; beverage bases in all menus; and commercial candy and hot pepper sauce in four menus. The MRE VIII was rated significantly better than MRE VII ($p < .001$). The dehydrated fruits (the only dehydrated item in MRE VIII) received a seven on the nine-point scale, indicating these products were very acceptable. The commercial candy (chocolate, etc.) got outstanding reviews. The inclusion of commercial products contributed substantially to troop morale. Merely seeing the commercial packaging made soldiers feel good because it reminded them of being home. The nine new entrees introduced with MRE VIII were also preferred over those offered in MRE VII.

(3) Both MRE VII and VIII contain 12 menus. The military may want to consider rotating different menus into the system every couple of years since acceptability is high when the products are initially introduced. In some instances acceptable products became unacceptable if eaten repeatedly over time[11].

(4) (1989): The MRE should come with efficient means to heat the meal. Flameless Ration Heating devices are now available, which are activated by two ounces of water and have been well received by the troops[12].

c. The following comments were obtained from laboratory and field evaluation of Australian rations.

(1) The Australians analyzed their 1984 rations. Some rations had excessive protein and salt. Certain rations were deficient in energy, ascorbic acid and thiamin. Ascorbic acid in fortified chocolate was found to have unsatisfactory storage properties. The proportion of energy derived from proteins was determined to be excessive in each of the menus. A desirable level is between 10 and 12 percent of energy derived from protein compared to 15 to 17 percent in the existing Australian rations. The protein level was twice that necessary for normal body function and if consumed by one man during one day would require 0.28 to 0.47 liter of water to excrete the protein metabolites. It was, therefore, recommended to reduce the proportion of meat in favor of cereals in some of the components making up the ration[13].

(2) This study comprised two field trips using questionnaires to gain objective data on acceptability of all food items in the Combat Ration, Ten Man (CR10M). At least 200 soldiers were required for each group. Group 1 soldiers were required to work very hard in extremes of temperature over 86°F (30°C) with little or no shade. Nights were clear and cool. Group 2 soldiers were doing infrequent periods of moderately hard work in a mild climate. The results were analyzed and combined. If there was a significant difference, both results were presented. The two items most commonly identified for deletion were beef and kidney, and luncheon meat. It was recommended that cheese, dried fruit, sweet biscuits and confectionery be used to boost the energy in the CR10M[14].

(3) Results of analysis of rations (1985) for moisture, fat, protein, carbohydrates, salt, ascorbic acid, niacin, thiamin, riboflavin, sodium phosphate, calcium, magnesium, iron, copper, zinc, lead and cadmium were given. It was found that certain components were energy deficient, deficient in calcium, magnesium, copper and some were not fortified with thiamin, riboflavin, niacin, or ascorbic acid[15].

d. The British have four types of operational ration packs. Two rations are designed for 10-man and 4-man group feeding and two for general service and arctic individual feeding. The 10 and 4-man rations with bread or biscuit supplement contain 4000 kcalories. The general service ration has 4000 kcalories and the arctic ration 4500 kcalories. All rations furnish (as percentage of calories) about 12% protein, 33% fat and 55% carbohydrate[16].

e. In Methods for Evaluation of Nutrition Adequacy and Status, it is clear that inadequate food intake is one of the important factors in the pathogenesis of malnutrition observed following injury. Some aspects of nutritional problems of seriously wounded soldiers are discussed. In addition, this book contains numerous articles by investigators evaluating protein adequacy, vitamins, and mineral adequacy in military rations by animal studies[17].

4. Dehydration Studies.

a. A review of the Bright Star Exercise conducted in Egypt (1983) noted the following causes of dehydration: inadequate supply of water; depletion of the body's salt content; and voluntary dehydration, due to inadequacy of the thirst mechanism. Voluntary dehydration increased with sweat rate and higher ambient temperature or work rate. Dehydration also increased with the temperature of the drinking water and the distance the soldiers have to walk to fill their canteens. Dehydration results in 2% to 6% loss of body weight as body water. Thirst usually occurs at a 2% deficit (1.5 quarts). Egyptians (1967) suffered 20,000 deaths with no wounds (apparent heat stroke). Chilling and sugar-based treatment increase water consumption. In the case of raw, unpalatable treated water, flavoring powder would be an asset. For example, the tested flavoring agent enhanced fluid consumption in five of seven units. Only 15% to 25% of individuals used hand-washing facilities. (There were no direct references concerning food in this report[18].)

b. A recent review entitled Environmental Medicine Support for Desert Operations contains the following practical guidance.

(1) Thirst does not occur until 1.5 quarts of body water are lost and this can occur within one hour of work. A loss of 3 quarts (two hours work) of body water, without drinking, produces weariness, irritability, loss of appetite, and sleepiness. Troop performance decrement is evident, leading to ineffectiveness. A 4.5 quart water loss without replacement (three hours work) results in dehydration casualties.

(2) Assure soldiers consume all rations to replenish calories lost by working and salt lost in sweating. Failure to replace salt, by skipping meals, leads to salt depletion, dehydration, nausea, vomiting and a variety of muscle cramps. Soldiers are impacted by the switch from garrison food and drink to field water and field rations and often dramatically reduce intake. Dehydration secondary to salt depletion is common within three to five days and has been observed in all prior conflicts.

(3) When water is not available, it is advisable to avoid eating food (i.e., salty or protein-rich foods) or taking salt in order to preserve retention of body water. Use a variety of food and food items. Monotony will be the biggest problem to develop over time. This reference (pages 6 to 8) contains an excellent review of food intake and potential nutrition problems summarized below.

(a) Soldiers reduce voluntary food intake by 20% to 40% when deployed to a field feeding situation. Body weight losses can have a significant impact on physical and mental performance.

(b) Food requirements do not diminish due to the heat. On the contrary, while the desire to eat is reduced, the actual amount of calories required increases.

(c) Monitor what the soldier eats and does not eat.

(d) View all weight losses as negative. Weight loss over 3% may negatively influence performance.

(e) Serve at least one hot meal per day. This is probably the simplest, most effective single event to help maintain voluntary food intake[19].

c. Additional comments from research articles pertinent to desert operations are given below.

(1) Items that encourage fluid consumption, i.e., chicken noodle soup, cocoa, and cider should be increased and unpopular beverage items should be reduced or replaced. Efforts toward better water discipline and forced drinking during operations should be implemented[20].

(2) The physics of heat transfer, physiology of human thermoregulation, pathophysiology of heat illness, and current concepts of prevention and management of heat illness were reviewed. Humans may be considered biochemical "furnaces," which burn food to fuel a complex array of metabolic functions. This "combustion" amounts to approximately 100 kcal/h for an average man (70 kg). Heat production may be increased 10 to 20 fold by strenuous exertion. Air is a good insulator; therefore, only approximately 2% of body heat loss is due to conduction. In contrast, the thermal conductivity of water is 32 times that of air; as a result, temperature loss during cold-water immersion is rapid[21][22].

(3) The energy from the sun is transmitted mainly in the form of light rays rather than infrared rays. Approximately 35 percent of these waves are reflected from the light skin but only a smaller amount from the dark skin. Consequently, in sunlight, dark skin absorbs more heat than white skin[23].

(4) Comments (2) and (3) are pertinent since increased body heat can reduce appetite and lead to secondary dehydration and/or weight loss resulting in impaired performance.

(5) It is often extremely important to acclimatize persons to extreme heat, (i.e., soldiers for tropical duty). Exposure of a person to heat for several hours each day while working a reasonably heavy work load will develop tolerance in about one week[23].

5. Food Metabolism in Hot Weather.

a. Intake requirements increase in hot weather. While little or no adjustment appears to be necessary for changes in environmental temperature at 68°F (20°C) to 86°F (30°C), people at 86°F (30°C) to 104°F (40°C) may require an extra caloric allowance to compensate for energy expenditures caused by increased metabolic rate, lower mechanical efficiency, and efforts to rid the body of excess heat, such as profuse sweating. Under these higher temperature conditions, an increase in caloric allowances of at least 0.5 percent for every degree of temperature rise above 86°F (30°C) is recommended (i.e., a 4000 kcalories demand at 86°F (30°C) would require an increase of approximately 200 calories at 106°F to 4200 kcalories)[23][24].

b. Appetite decreases in hot weather. When an animal (including man) is exposed to cold it tends to overeat, and when exposed to heat, it tends to undereat. These changes are caused by interaction within the hypothalamus between the temperature regulating system and the food intake regulatory system[23].

c. Diet considerations for hot weather.

(1) American diet. The average American receives approximately 15 percent of his or her energy from protein, about 40 percent from fat, and 45 percent from carbohydrates. In most parts of the world the quantity of energy derived from carbohydrates far exceeds that derived from both proteins and fats. In Mongolia, which includes the Gobi desert, the energy received from fats and protein combined is said to be no greater than 15 to 20 percent[23][25].

(2) Protein in diet.

(a) An average American can maintain normal stores of protein provided that his or her daily intake is above 30 to 45 grams[23].

(b) Military requirements. For military personnel within the reference weight range, protein recommendations are set between 48 to 63 g/day for males. These computed protein levels have been further increased to 100 g (3.53 oz) per day to adjust to usual intake patterns and to help maintain a high level of palatability and food acceptance among military personnel. A total day's protein intake of more than 100 g/day has not been shown to improve heavy physical performance[26].

(c) MRE protein content. Since the introduction of the improved MRE (MRE VIII), the MRE contains 12 menus having an average protein content of 48.60 g. Hence, three MREs a day would provide 145.8 g of protein. Assuming all is consumed, this is approximately 50% more than the 100 grams per day prescribed by the Military Recommended Dietary Allowances. The MRE X for three meals contains 3924 calories versus a recommended 3600 calories per day as stated in AR 40-25. Overall the

MRE X has an average caloric breakdown of 15 percent for protein, 36 percent for fat, and 49 percent for carbohydrates[27].

(d) Protein diet considerations in hot weather. Consideration of reducing protein content in military rations during hot weather has been noted in military historical records. For example, a review from 1787 to 1818 noted

> The quantity of meat in hot weather or hot climates should be diminished and vegetables should be issued in lieu[28].

A further review in 1918 states

> We are now faced with the question of what should be the optimum amount of protein in the ration....there is much evidence that muscular work can be derived from carbohydrate food, especially from sugar, and this doubtless explains the craving of men in training for sweets. These facts indicate a relatively small amount of protein or meat in the diet would be sufficient. There are some facts which deter us at present from reducing the 3/4-pound daily meat ration. First of all is that meat stimulates heat production in the body more than any other food stuff[28].

(e) The above comments concerning the production of excessive heat during the metabolism of proteins are supported by more recent nutritional studies. The rise in metabolism after eating carbohydrate food is only six percent of the total food value (i.e., six calories for each 100 calories of carbohydrates consumed) and the increase caused by fat is not very different in magnitude. However, the rise in metabolism after taking 100 calories of protein is much greater, amounting to about 30 percent. If the diet contains a great deal of meat, the day's increase in metabolism may amount to 18 percent or even more. The extra energy set free in the body is of little or no use, because it cannot be used for doing work and simply generates excess heat, a detriment in hot climates[24].

(f) The above comments stress the importance of avoiding high protein diets in high heat stress environments to include not only hot ambients such as deserts but for personnel encapsulated in Mission Oriented Protective Posture (MOPP) gear.

6. Metabolism of Food.

a. Extraction of Energy. In the first stage, large molecules in foods are broken into smaller units. The resulting amino acid, simple sugar, and fatty acid are then converted into primarily acetyl CoA, which is used to generate energy through the citric acid cycle and the electron transport chain[29].

(1) Water is required to metabolize protein. The production of acetyl CoA from an amino acid requires water for deamination. Water is also required to convert the amino group into urea. Overall, three molecules of water are consumed to produce one molecule of urea. Further, water may be required to excrete the urea and resulting organic acid. In addition, four high-energy phosphate bonds (ATP) are consumed in the synthesis of one molecule of urea, requiring the expenditure of energy, which generates heat. There are also over 10 degradation pathways used to metabolize excess amino acids. These facts offer a biochemical explanation of why anecdotal evidence indicates soldiers in past conflicts in hot climates have tended to reject excessive protein in their diet. Although approximately 750 mls of water are required for metabolism and renal excretion of 100 grams of protein, excess protein will not cause dehydration if enough water is supplied[30,31,32].

(2) When a fatty acid molecule is hydrolyzed to produce an acetyl CoA molecule, one molecule of water is needed. Further, metabolism of the acetyl CoA via the citric acid cycle and the electron transport chain produces considerable energy and water. Water is always one of the products formed when fuel foods are burned and may amount to a pint per day[24]. The theoretical amount of metabolic water expected is actually several fold greater than the reported one cup. This discrepancy represents an area meriting further investigation to assess the significance of metabolic water.

(3) When a sugar (glucose) molecule is converted to acetyl CoA, a net total of two high-energy molecules (ATP) are generated and two molecules of water are produced. This water and energy are immediately available to the cell. The fluid medium of all cellular protoplasm is water, which is present in a concentration between 70 and 85 percent[23]. Overall, when one molecule of glucose is completely oxidized, 42 water molecules and 36 ATP molecules are produced. On a metabolizable energy basis, such as acetyl CoA molecules derived from constituents, glucose is actually superior to fat in producing energy and water[29,33]. Glucose is stored in the muscle and liver as glycogen which serves as a source of energy and water.

b. The value of a high carbohydrate diet in hot climates.

(1) Carbohydrates appear to be superior to fats and amino acids for producing energy and water during metabolism in hot climates. Fats are very nonpolar and so they are stored in a nearly anhydrous form, whereas glycogen binds over two grams of water for every gram of glycogen. By weight, fats can store more than six times as much energy as glycogen[29]. However, when 500 grams of muscle glycogen are metabolized during prolonged exercise over a period of four to six hours, up to 1,500 mls of water are produced. Studies have demonstrated that when muscle glycogen reserves are increased to 500 grams, body water content increases from 45.8 to 48.0 liters (a 2.2 liter water store).

When the glycogen is metabolized for work performance the liberated water helps prevent a reduction in the plasma volume from sweating[34,35]. In round figures, the average physiologically available energy (kcalories) in a gram of the three different foods stuffs in the diet is: carbohydrate (4.0), fat (9.0), and protein (4.0)[22]. The conventional calorie is technically a kcal. Overall, daily energy should be derived primarily from carbohydrates in the diet with fat in reserve. A typical 70 kg man has a fuel reserve of 100,000 kcal in triacylglycerols, 25,000 kcal in protein, 600 kcal in glycogen, and 40 kcal in glucose[29].

(2) Carbohydrate is a fat sparer and a protein sparer; that is, carbohydrate is burned in preference to the burning of fat and protein, and this is especially important for preserving the functional proteins in the cells[23]. However, during a period of starvation, the carbohydrate reserves are exhausted in only a day. The brain requires a blood glucose level above 50 mg/100 mL; hence, the first priority is to provide sufficient glucose to the brain and other tissues. Only the glycerol moiety of triacylglycerols can be converted into glucose and only a limited amount is available. The only other source of glucose is amino acids derived from the breakdown of protein. Muscle is the largest potential source of amino acids during starvation. However, the second priority in metabolism is to preserve protein. This is accomplished by shifting the fuel being used from glucose to fatty acid and ketone bodies. After several weeks of starvation, only 40 g of glucose is needed per day for the brain, compared with about 120 g in the first day of starvation. The muscle breakdown after several weeks is 20 g, compared with 75 g per day early in starvation[29]. Hence, in the early stages of dietary carbohydrate and protein deficiency, muscle protein is degraded to ensure adequate blood glucose levels are maintained. Excessive carbohydrate in the diet is stored as glycogen and fat; however, glucose cannot be adequately derived from fats, as noted above[33].

(3) Carbohydrates have been the primary food staple of desert people for centuries. From the literature, it was found that the diet of Bedouin Arab tribes living in the Sahara consists of

> yogurt and rice pilaf containing shreds of lamb, kid or chicken, hard biscuits called kak, and, during a feast, roast sheep or goat. However, the date is the chief of all the foods among the desert people. The Arabs of the desert eat wild honey, feed abundantly on locusts when they can, feast eagerly on the big lizards that dart among stony places, and do not disdain even the jerboa (Kangaroo rat). But the great article of diet is the date. Nothing is so abundant as dates. Sometimes for many weeks nothing else will be eaten in an Arab tent, and even the donkeys and camels are fed on this fruit[25].

(This diet is quoted from a reference dated 1950, and captures the cultural diet for the past hundreds of years without influence of oil riches.) Dates are a fruit having a high concentration of carbohydrates. For example, a 1 oz (28.35 g) portion of dates contains 86.5 calories and 21 g of carbohydrate versus 9.8 calories and 2.5 g of carbohydrate for oranges or 14.6 calories and 3.7 g of carbohydrate for apples[36].

7. Stability and Storage of Food in Hot Climate.

a. Stability of nutrients. The following comments are extracts from research studies of the past 30 years. Generally, they illustrate that if food is stored in the desert at approximately 100°F (38°C) for over one month, loss in quality and nutrients will result.

(1) To test the hypothesis that NISIN (an antibiotic) will prevent thermophilic spoilage, three products were stored with and without NISIN under four conditions of storage, giving a total of 24 lots. Thirty-seven percent of the cans of green peas without NISIN underwent thermophilic spoilage after two weeks when stored at 131°F (55°C) as compared to those with NISIN which showed no evidence of thermophilic spoilage at 131°F (55°C). It was recommended that care be taken to store canned foods under 104°F (40°C), having them stacked off the ground and under covering allowing ventilation especially across the top of the stack. Canned foods should not be stored in the field under high solar loads under closed wraps. The addition of NISIN to low-acid canned foods would be appropriate if cans cannot be stored at less than 104°F (40°C)[37]. A review of the use of NISIN as a food preservative was given[38].

(2) A study was conducted of the stability of vitamins occurring in appreciable amounts in 13 representative canned foods (apricots, orange juice, tomato juice, carrots, peas, spinach, lima beans, green beans, whole kernel yellow corn, cheese spread, dried whole milk and evaporated milk) through 18 months storage at 70°F (21°C), 90°F (32°), and 100°F (38°C). Thiamine and ascorbic acid were the most labile, losing approximately 80% and 90%, respectively, at 100°F (38°C). Niacin, folic acid, vitamin A and carotene showed no significant loss[39].

(3) Experiments were conducted by the Quartermaster Food and Container Institute and the University of Georgia to determine storage life of 59 ration items. Storage was continuous for various periods up to seven years at 100°F (38°C) in 50% to 90% relative humidity (RH), at 70°F (21°C) in 50% to 90% RH and at 47°F (8°C), 32°F (0°C), 0°F (-18°C), -10°F (-23°C), and -20°F (-29°C). Fifty-two charts showing the relation of quality score to storage time at six temperatures were shown. Ice cream dry mix, high in sugar, fat, and protein, but low in moisture, was stable and relatively acceptable for up to seven years when stored at -20°F and 0°F; however, the mix became unacceptable when stored at 70°F (21°C) or 100°F (38°C) for three years[40].

(4) Figures were given for concentration of vitamins A, B1, B2, B6, B12, C, folic acid, and niacin in a processed cereal product, determined at monthly intervals during one year of storage at room temperature (approximately 75^{o}F). Vitamin A was least stable, losing 50% of its activity over one year, followed by C (40% loss), B2 (23% loss), folic acid (19% loss), and B12 (17% loss). B6, B1, and niacin were completely stable over the period[41].

(5) The effects of heat sterilization and prolonged storage on the nutritional value of six canned meals used by the Dutch Army were analyzed. The determinations for vitamins, amino acids, and protein utilization in rats, from foods before and after sterilization and storage for three and five years were made. Considerable losses occurred in the vitamin A, thiamine (B1), niacin, and pantothenic acid, both during sterilization and storage, whereas E, riboflavin (B2), pyridoxine (B6), folic acid, choline chloride, and inositol were relatively stable. Protein quality of most products decreased slightly during sterilization and showed a further steady decline during storage. Amino acid patterns on all products showed a slight decrease in lysine during sterilization[42].

(6) Previous studies have shown that prolonged storage of whole-milk powder at temperatures below 100^{o}F (38^{o}C) showed little or no change in the content of the B-complex vitamins. Storage at 140^{o}F (60^{o}C) caused rapid destruction of folic acid (53% loss at four weeks), and slower loss of thiamin, B6, pantothenic acid (18% at eight weeks). There were no changes in riboflavin, biotin, nicotinic acid and B12.

(7) Spray-dried whole milk containing 40 grams of water per kilogram was stored at 90^{o}F (37^{o}C) in nitrogen and oxygen. Loss of folate (72%) and vitamin C (91%) occurred after 30 days stored in oxygen, but no loss was shown after storage in nitrogen. At 158^{o}F (70^{o}C), the destruction of the four labile vitamins was much increased; 18% or less survived at four weeks. The loss of Vitamin B6 and thiamin was much greater at 100 g moisture per kilogram than at 40 g/kg moisture content[43].

b. Storage of foods. The following summaries or excerpts from research articles are cited, illustrating the need to store food in shaded, ventilated areas.

(1) Air temperature over large stacks of uncovered food in desert regions reached 108-112^{o}F (41-44^{o}C) daily. Product temperature ranged from 98-100^{o}F (36-38^{o}C). Tightly covering stacks of food with a tarpaulin caused the temperature of the products to rise to 111-113^{o}F (44-45^{o}C) on top, but it remained near 98^{o}F (37^{o}C) at the bottom. The average temperature for storing military rations in desert regions was about 100^{o}F (38^{o}C)[44].

(2) Comparative food storage temperatures were studied at 18 positions, located in empty and loaded boxcars positioned at Yuma, Arizona and Cameron Station, Virginia. Detailed outer and inner wall surface temperatures were reported along with temperature distribution data. Radiation and heat barrier insulation reduced maximum temperature 10-15°F (-12 to -9°C), and mean temperature five degrees in the more severe Yuma storage. The relation between mean storage air temperature, and outside temperature correlated, allowing predictions of food storage life. The cars were loaded with canned string beans and C rations. Air six inches below the roof was 149°F (65°C); outside maximum temperature was 110°F (43°C); air in top center carton was 117°F (47°C); food in top carton was 112°F (44°C); and food in middle buried carton was 98°F (37°C); graphs and tables were included(45).

(3) The relationship between storage temperature and shelf life for many foods in normal ranges of temperature may be roughly described:

$$\log y/y_o = 0.0167(T-T_o)$$

y = reaction rate at T (°F)
y_o = reaction rate at T_o (°F)
T = mean storage temperature (°F)
T_o = storage temperature at which reaction rate is known.

This relationship predicts that a decrease of 5°F (2.8°C) in storage temperature will result in a 21% increase in storage life, while a 10°F (5.6°C) decrease will result in a 47% increase. Therefore, lowering warehouse temperature, particularly in the 70°F (21°C) to 100°F (38°C) range, results in substantial gains in storage life. Refrigerated systems could not be justified, so nighttime ventilation using two one-hp exhaust fans and daytime insulation were used. This procedure reduced temperature 4.25°F (2.4°C), thereby increasing storage life 18%. Detailed analysis of temperature at 16 positions in the storage area and in food containers in two boxcars (nonventilated and night ventilated) for three years are given(46).

(4) Temperature is the most important storage factor affecting the quality and acceptance of packaged, stored food. A detailed study described hourly temperature distribution at nine positions in cartons in four differently exposed storage dumps during July 1955 at Yuma, Arizona. The mean storage temperatures for the top, center carton air for the 43-day period were as follows: tight cover stack: 101.8°F (39°C); open stack: 90.8°F (33°C); raised fly stack: 89.4°F (32°C); and raised fly with foil stack: 88.5°F (32°C). A doubling of food degradation rate for every 18°F (10°C) was assumed(47). The literature was reviewed with respect to high-temperature stress for a wide variety of service material, including food(48).

8. Conclusions.

a. The climatic conditions in the ODS area of operations tend to exacerbate personnel dehydration and accelerate deterioration of stored food products.

b. The desert operating conditions place a higher than usual energy requirement on personnel. Water and other liquid requirements are very high. Dehydration with serious performance and medical sequelae can occur rapidly.

c. The thirst and hunger mechanisms of individuals in the desert do not stimulate these personnel to consume adequate amounts of food or water.

d. Acclimatization to the desert environment requires about one week. "Burn out" of personnel operating in the ODS area is estimated to occur in one year or less.

e. The best macronutrient mix for desert operations and for other high heat stress environments such as encapsulation in MOPP gear, appears to be a balance of low protein (around 50 to 100 grams/day), moderate fat and high carbohydrates. The current U.S. military ration, <u>if totally consumed</u>, will provide approximately 50% more protein than the recommended 100 grams/day.

f. Hot meals, cool-flavored beverages, and adequate rest tend to stimulate appetite and ensure proper hydration. Micronutrients (i.e., vitamins) tend to be lost with prolonged storage at high temperatures.

g. Dehydration due to salt depletion is a common phenomenon in desert operations. Adequate intake of rations will prevent salt depletion. Some additional salt <u>in the diet</u> may be necessary depending on the sodium content of potable water.

h. Control of storage temperatures has a dramatic impact on shelf life and quality.

i. Rations stored in the open or under cover without insulation and ventilation reach very high temperatures, particularly in the top layers.

j. Field sanitation is particularly important to disease prevention in a hot environment. High temperature encourages microbial activity.

k. Excess protein appears to be inappropriate in the hot weather environment due to the water demand it creates for metabolism and excretion. In addition, such protein generates excessive body heat, which can be detrimental to individuals working in hot climates or in high heat stress environments such as when encapsulated in MOPP gear.

9. Recommendations.

a. Personnel Management and Feeding Practices.

(1) Flameless Ration Heaters should be given widest distribution to increase availability of hot meals to enhance consumption. Although improvements made to the MRE have significantly increased

acceptability/consumption, the ability to heat the entree further increases its acceptability to the soldier.

(2) A ration feeding of lower protein and higher carbohydrate meals, should be introduced whenever tactically feasible.

(3) Fruit juices should be made widely available.

(4) Ice packets should be provided using potable water.

(5) Commanders should monitor troops to ensure water and food intake is adequate and sanitation procedures are followed. View all weight losses as negative.

(6) Lister bags, which cool drinking water through porous evaporation, should be made available.

(7) A one-week acclimatization period with reasonably heavy duty for several hours daily should be given to personnel entering in hot climates.

(8) Training to encourage proper hydration and nutrition in the desert should be given high priority.

(9) Desert food supplements should be predominantly complex carbohydrates. Snacks high in protein or fat should be avoided.

(10) Meals should be provided at the coolest times feasible: early morning, late evening.

(11) Field sanitation to avoid food-borne disease should be emphasized.

(12) At least one hot meal a day will do a great deal toward ensuring adequate nutrition.

(13) Use of familiar, commercial food items where possible boosts morale and helps increase voluntary nutrient intake.

b. Future studies.

(1) MRE X or later production of MRE should be evaluated in hot climates to determine if soldiers lose an unacceptable amount of body weight. Two groups should be evaluated, one having three MREs daily versus one having two group meals (A, B, or T) and one MRE for lunch. Such evaluation would be similar to MRE studies in 1986 and 1988.

(2) Since the MRE X may have a protein content slightly higher than necessary in a desert environment, the use of supplements high in carbohydrates should be considered. The current 12 MRE menus could be

expanded to 18 to include six additional menus with high complex carbohydrate, low protein, and moderate fat content. Alternatively, dried fruits and dates could be used as supplements to MREs, but the acceptance of these items by troop may not be high.

(3) In order to provide additional opportunity for testing, studies could be conducted in Australia in January or Yuma, Arizona in July since temperature conditions would be equivalent to the ODS area. MRE X could be evaluated as described above as well as a third group containing redesigned MREs with a high percentage of complex carbohydrate content.

(4) Analytical studies should be pursued to identify chemical changes in food with storage time/temperature.

(5) Vitamin stability should be assessed in MREs held at 100°F and 120°F for 30 days.

c. Storage of foods in hot climate.

(1) Cartons should be marked "heat sensitive items - keep out of sun - store in ventilated shade."

(2) Time-temperature sensors should be used to visually indicate temperature abuse.

(3) Avoid closed storage containers (i.e., International Standards Organization containers) if possible. Have top layer of boxes empty as insulation. Avoid tightly covering boxes with tarpaulins without ventilation. Rather use tarpaulins to shade and leave with space underneath to ventilate.

(4) In so far as possible, product should be stored IAW DOD Manual 4145.19-M-1, so as to maintain product at as low and stable a temperature as possible. In the desert environment such field-expedient measures as covered underground storage or use of empty cartons, sand bags or other readily available insulation material on top of stacks of rations can contribute immeasurably to maintaining product quality. For staging areas in the desert, pallets of subsistence could be covered on top and sides with empty MRE cartons or other available insulation. Reflective material (foil) could be placed over the insulated pallets and the staging area could be further protected from direct sunlight with an over-covering of camouflage. Use of reflective material should be incorporated only in those circumstances where signature considerations from such a source are not an issue.

(5) Rapid turnover of food to avoid storage in the heat should be normal management philosophy. Bulk storage of food outside of the high heat environment, with subsequent rapid movement forward and rapid turnover, will promote high-product quality and encourage consumption.

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