ABSTRACT

Time-temperature exposures of each stage of the preparation of kalua pig, laulau, pipikaulua beef, and taro leaves in coconut milk were evaluated at two Hawaiian-style restaurants. The temperatures attained at the geometric center of these foods during cooking were such that vegetative pathogenic foodborne bacteria (but not spores) would have been killed, had such organisms been present. Hot-holding and reheating procedures included no obvious hazards. leftovers refrigerated in one establishment, cooled slowly; leftovers in the other establishment were kept at room temperature overnight. Procedures are recommended to minimize the chances of the foods becoming contaminated after cooking, to cool the foods more rapidly and to reheat leftovers thoroughly.

Foods prepared in the Hawaiian or South Sea Island style have been reported occasionally as vehicles in outbreaks of foodborne disease in the United States (6). During the period from 1963 to 1968, establishments serving Hawaiian foods represented only 2% of the total of all foodservice establishments in Hawaii, but 7 outbreaks, 21% of the reported outbreaks, stemmed from foods prepared in these establishments (Hawaii State Department of Health surveillance data). Chicken long-rice and kalua pork were reported as vehicles in outbreaks of Clostridium perfringens enteritis; kalua pig, a vehicle in an outbreak of staphylococcal food poisoning; and boiled hog viscera and long-rice and kalua pig were reported as vehicles in outbreaks of salmonellosis. Since that time laulau and pot have been reported as vehicles on two occasions (6). Kalua pig has also been responsible for a large outbreak of C. perfringens type C enteritis necroticans ("pig bell") in New Guinea (5).

Because of this history of outbreaks and because improper handling, storage and serving practices have been observed at luaus and in some restaurants that serve Hawaiian-style foods, a time-temperature survey of preparation operations was done in two Hawaiian-style foodservice establishments in Hawaii. One of the operations was at a large resort-type hotel which held luaus three to four times each week; the other was a small restaurant that served Hawaiian-style foods.

MATERIALS AND METHODS

Operations

Two pits in a 6 m (20 ft) square rock-walled structure called an imu were used to prepare kalua pig in the traditional manner. Porous oval volcanic stones were put in one and kiawe (Prosopis pallida) wood was stacked among and around them where it burned for several hours. Meanwhile the space between the chest and the forelegs of an eviscerated porcine carcass [approx 61.2-63.5 kg (135-140 lb) dressed weight; length 127 cm (50 in); girth 99 cm (39 in); chest height 30.5 cm (12 in); leg height 66 cm (26 in)] was slashed longitudinally on both sides and the brisket was slashed deeply along the median from neck to bone. Smaller slits were also made randomly in the periphery of the carcass and salt was rubbed into them. Some of the heated stones from the fire pit were put into the bottom of a second pit called an imu. This pit was lined with a layer of shredded banana stumps and stems and then lined with ti (Cordyline) leaves. Heated stones were also put into the visceral cavity and the three newly formed cavities of the carcass; the carcass was then closed and tied and bound in wire fence-mesh to secure it. The prepared carcass was laid on top of ti leaves in the pit and more ti leaves were put upon and around the carcass, which was then covered with banana leaves, and damp burlap or canvas was spread over the leaves. Earth was then shoveled to a depth of approximately a foot over the covered carcass.

After cooking about 7 h, earth, canvas and leaves were removed from the pit and the stones were removed from the cavities. The cooked carcass was put into a large wooden box and taken into a kitchen where it was deboned and picked from fats and oils. Skin and fat were stripped from the cooked pork and the meat was put into stainless steel pans. These pans were kept in a warming cart until put on the serving line where their temperatures were maintained by sterno-fueled heaters.

The restaurant cooked kalua pig in an oven. Frozen pork butts were thawed in a pan at room temperature, transferred to another pan lined with ti leaves, salted, covered with ti leaves and cooked about 6 h in an oven at 121°C (250°F).

The restaurant also prepared laulau, a mixture of black sable fish and pork wrapped first with taro leaves then with ti leaves. This dish was cooked in a pressure cooker and left at room temperature until shortly before serving when it was reheated in a steamer and put into a water-bath "steam" table.

1 Centers for Disease Control.
2 Hawaii State Department of Health.
At the restaurant, luau sauce (taro leaves) was cooked and left at room temperature several hours before being either refrigerated or reheated; coconut milk was added before serving with octopus or other seafood.

Also at the restaurant, pipikalua beef (thin beefsteak strips) was prepared by being hung over a range overnight to start drying. The drying continued the following day while other foods were cooked on room temperature several hours before being either refrigerated or heated on a griddle.

Measurements

Temperatures were measured with thermocouples and recorded on a recording potentiometer. Specifications for this instrument have been published previously (1,2). Needle-probe thermocouples were inserted into the thickest portion of the hindquarter and forequarter of the carcass and a button-type thermocouple was attached to the skin at one side. Needle-probe thermocouples were inserted into the geometric center of pork butts, laulau and pieces of pipikalua beef and were also suspended into the geometric center of luau sauce in a pan. Welded-junction thermocouples were used to measure air temperatures.

Laboratory analyses

Samples were collected as described by Bryan et al. (3,4). Laboratory procedures for the isolation of C. perfringens, Salmonella, and Staphylococcus aureus followed those described in the Bacteriological Analytical Manual (7).

RESULTS AND DISCUSSION

Hotel (imu-cooked) kalua pig

The cooking of traditionally prepared kalua pig is accomplished mainly by the steam that is created as the hot stones vaporize moisture in the meat and the surrounding stems and leaves. In this investigation, the surface of the carcass reached 93°C (200°F) in about 15 min. A temperature of 74°C (165°F) was reached in the carcass forequarter after a lapse of about 2.75 h, and in the hindquarter after about 3.5 h (Fig. 1). The internal temperature of the carcass was about 96°C (205°F) after 7 h in the imu. This is inconsistent with data gathered by Murrell et al. (5) in New Guinea which suggested a much shorter (1.5 to 2 h) cooking time, but the internal temperature measurement of porcine carcasses cooked in imus varied widely during that investigation.

Leftover pork was put into stainless steel pans (20" × 12" × 4"), covered with plastic film and stored either in a walk-in refrigerator or in a walk-in freezer. The temperature at the geometric center of the pork in the freezer fell to 7°C (45°F) only after 9 h had elapsed. The same temperature was reached in the pork in the refrigerator after a lapse of 14 h (Fig. 3). As shown in previous studies (1,2,4), cooked meat, even when arranged in relatively shallow layers, cools slowly in covered pans despite the low temperature conditions of refrigerated storage.

Leftover pork was often mixed with cabbage, spices and water. This mixture was brought to a boil then served in the staff cafeteria. (This practice was witnessed and boiling was observed, but temperatures of this product were not taken.) When a particularly large number of persons attended a luau, leftover pork was heated in a steamer and served. (Although this practice was not carried out during the survey, vegetative pathogenic bacteria would be killed if the leftovers reached temperatures of 74°C (165°F) or more during reheating.)

Restaurant (oven-cooked) kalua pig

Temperatures of the geometric centers of pork butts cooked in ovens reached 74°C (165°F) in about 2.5 h and 99°C (210°F) in about 4 h during cooking and

![Figure 1. Temperatures of kalua pig (pork) [61.2-63.5 kg (135-140 lb.)] during cooking in an imu.](http://example.com/figure1.png)

![Figure 2. Temperatures of pieces of kalua pig during stripping from bones and holding in a warming cart for serving.](http://example.com/figure2.png)
Temperatures higher than 85°C (185°F) were maintained in one batch of the pork during hot-holding (Fig. 5). Temperatures near the top of a second batch of pork were at 65.5°C (150°F) during hot-holding (Fig. 5). Leftover pork was put on a table in the dining room for overnight storage. This meat was quite hot when it left the steam table so the temperatures at the geometric centers of these pieces took about 5 h to fall far enough for common foodborne pathogenic bacteria to grow (Fig. 6). The germination of any spores and the growth of resulting vegetative bacteria would, therefore, be delayed. But during the next 5 h on the table, the meat was within a range that promotes rapid growth of bacteria and any common foodborne pathogens present would have thrived. Risk would have been increased if the pork had been only warm at the start of the cooling period.

Neither Salmonella nor S. aureus was isolated from three samples of kalua pig, but 80,000/g C. perfringens was recovered from one of the samples that had been kept at room temperature overnight.

Meat stew, also prepared in the restaurant, was within a temperature range in which common foodborne pathogenic bacteria could multiply rapidly for about 7 h (Fig. 6).

The leftover foods were reheated the morning after overnight storage at room temperature. Temperatures at the center exceeded 93°C (200°F) at the completion of reheating (Fig. 5). These temperatures would kill any vegetative pathogenic bacteria that had been produced during the overnight period of storage, but they would destroy neither staphylococcal enterotoxin nor Bacillus cereus emetic toxin, if present.

Pipikaulua beef

Pipikaulua beef reached a temperature at the geometric center of 64°C (147°F) during drying (Fig. 7).
Temperatures exceeded those of the room air only during the period that foods were cooked on the range below the hanging beef. The geometric center of a 0.5-oz piece of pipikaulua beef reached 74 °C (165 °F) within 1 min and 97 °C (206 °F) in 100 s during heating on the griddle. Psychrotrophic microorganisms could grow on the surface of the drying meat before its water activity dropped to a growth-prohibitive level; however, final cooling would probably kill any resulting population of vegetative bacteria.

Taro leaves in coconut milk

During cooking, taro leaves reached temperatures that exceeded 94 °C (200 °F). The cooked mixture cooled slowly while kept in the cooking pots at room temperature (Fig. 8) and the rate of cooling changed only slightly during subsequent storage in a refrigerator (Fig. 9). Microorganisms could have grown and multiplied during the period at room temperature and initially during refrigerated storage.

Laulau

Although high temperatures were reached while cooking and holding laulau in a steamer (Fig. 10), there was potential for germination of spores and for multiplication of resulting vegetative cells during subsequent storage at room temperature (Fig. 11) and later during the initial period of storage in a refrigerator (Fig. 11). The taro and ti leaves wrapped around portions of the meat and fish inhibit cooling but they also are a barrier to contamination. During reheating, temperatures within the laulau slightly exceeded 100 °C (212 °F) within 1.25 h. This range of temperatures would kill those vegetative cells that germinated from spores that had survived cooking and that had multiplied while the food was cooking. However, neither B. cereus emetic toxin nor staphylococcal toxin, which could have been produced if the surviving organisms had been either B. cereus or S. aureus, would have been inactivated. Neither S. aureus, C. perfringens, nor Salmonella was isolated from four samples of the laulau.
CONCLUSIONS

Hawaiian- (South Sea Island-) style foods are, when prepared in the usual way, cooked thoroughly so the critical control points of the operations are prevention of opportunities for these foods to become contaminated and cooking. There were opportunities for these foods to become contaminated after they had been cooked. Therefore, these foods should be handled only by persons wearing disposable plastic gloves or with clean utensils. These cooked foods should only be allowed to contact equipment that has been thoroughly cleaned and disinfected since they last contained or touched raw food.

Cooked foods should not be left at room temperature except for short periods immediately after having been cooked, periods during which the food temperatures remain above 55 C (131 F). These foods should be kept above this temperature during holding and they should be cooled rapidly. Cooling practices in the two establishments that were surveyed would permit germination of spores (if they were present) and multiplication of vegetative cells that either had emerged from the spores or were post-cooking contaminants. Therefore, unremitting perserverance is required to ensure that foods are cooled rapidly before being refrigerated and to ensure that they are arranged in shallow layers to further speed cooling during the initial period under refrigeration, or to cool them in rapid-cool refrigerated units (2,3).

Finally, leftover, chilled foods should be thoroughly reheated so that internal temperatures reach at least 74 C (165 F) before being served.

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