MUTLI-MATERIAL FOOD PRINTING WITH COMPLEX INTERNAL STRUCTURE SUITABLE FOR CONVENTIONAL POST-PROCESSING

Jeffrey Lipton[1], Dave Arnold[2], Franz Nigl[1], Nastassia Lopez[2]
Dan Cohen[1], Nils Norén[2], Hod Lipson[1]
[1]Cornell Computational Synthesis Lab, Department of Mechanical and Aerospace Engineering, Cornell University, Ithaca NY, 14853
[2]The French Culinary Institute, New York, NY, 10013
Reviewed, accepted September 23, 2010

Abstract

Solid Freeform Fabrication (SFF) of food provides an exciting application for additive manufacturing technologies. A variety of materials has been used to demonstrate food printing. However, these materials were not suited for traditional food processing techniques (Baking, slow cooking, frying, etc) and thus eliminating the majority of today's consumed food. We demonstrated new materials suitable for baking, broiling and frying. Turkey, scallop, celery were processed and modified using transglutaminase to enable them to be slow cooked or deep-fried after printing. Mutli-material constructs of turkey meat and celery were successfully printed. A cookie recipe was modified to be printable while retaining shape during baking. By adding cocoa powder to the modified recipe a second, visually and differently tasting material was created. A complex shape of the cocoa modified material was printed within a block of the modified material. The complex internal geometry printed was fully preserved during baking.

Introduction

Solid Freeform Fabrication of food is a potential "killer application" for the field. Few things excite the popular about SFF as printing food. Recently the concept printer called "Moléculaire" was a finalist for the Electrolux Design lab 2009 competition (1). The concept model from MIT called "Cornucopia" received a slew of media attention for proposing a similar idea (2). Both machines are merely concept drawings, completely non-existent. Despite not existing, people are intrigued because of the potential impact SFF could have on food as our society knows it. The potential for SFF's impact on food was well examined in the paper "Hydrocolloid Printing: A Novel Platform for Customized Food Production" from the 20th Solid Freeform Fabrication Symposium. (3)

There are two key limiting factors preventing the acceptance of SFF of foods. One key barrier is the material set requirement. Many SFF machines use only a limited subset of materials, changing the materials is commonly manually preformed. Fab@Home 3d printers are capable of using an unusually wide variety of materials, however they still require a user to switch materials when called for. The second barrier is integration into traditional food environments. Chefs, the majority of whom are adults cooking in their house, want a new technology to complement current techniques. Printable food material must be compatible with traditional cooking techniques such as broiling, baking, or frying. No previous work on SFF of food has attempted to process the printed constructions with traditional cooking techniques

Background

Previous work on the solid freeform fabrication of edible constructs used unmodified traditional foods. These efforts relied on the direct fabrication of final food forms. No post processing was required except for cooling of the material. The initial work in food SFF relived on traditional materials. Frosting, cheeses and chocolate were allowed to cool in an uncontrolled fashion (4). The print properties of chocolate have been studied and characterized extensively. (5) While printing chocolate required that it be heated to retain its liquid state, the print process was the final step in preparation of edibles.

Other attempts as printing edible constructs focused on the use of nontraditional edibles such as hydrogels. They allow a machine to use a small space of base materials to generate a large space of printable materials, potentially solving the material set problem. SFF of hydrogels could allow for the complete control of the final products taste, nutritional value, and texture (3). The edibles made using hydrogels received no further post processing. Using such controlled food is typically reserved for medical and space applications. Such highly controlled food would not be immediately adopted into the homes of most individuals. Hydrogels may be practical in the future, but much more work is needed to replicate the depth and breadth of current cuisine, and ensure their acceptance.

Modern cooking offers a wide variety of additives to modifying traditional foods. These additives are often natural extracts which have been distilled or refined. These additives have been used to make a wide variety of common foods such as sausages. It is also used to make exotic cuisine like shrimp pasta. (6) In this paper we examine the application of Transglutaminase and Agar for modifying printable food recipes.

Methods: Modified Traditional Recipes

Printing a cookie was selected as a demonstration of the ability of SFF'ed food to survive baking. The printed cookie needs to have a complex shape during the print process, and retain the shape after packing. Conventional cookie recipes can be 3d printed into complex shapes. In figure 1a Pillsbury sugar cookie dough was extruded into the shape of space shuttle using a Fab@Home 3d printer with a displacement tool. Unfortunately butter or shortening in traditional recipes tend to liquefy when baked, causing the shape to be lost (figure 1b). By modifying a traditional recipe it should be possible to create a recipe

A modified traditional cookie recipe from Austria called "Weihnachtsbaeckerei" was selected as a base recipe to make shape retaining cookies. Weihnachtsbaeckerei were selected as a base since they retain shallow 2.5D shapes though they cannot hold complex 3d structures. A novel geometrically stable recipe was created by modifying the ratio of ingredients from the traditional recipe. Novel recipes were tested by baking handmade cubes.

(a) (b)

Figure 1: Common cookie recipes are printable(a), but the printed geometries do not survive backing(b).

Methods: Additives

Transglutaminase was examined as a food additive which can allow for the construction of complex geometries out of meat. Two candidate meats purees were selected as test material. Scallops are a common shellfish used in cooking in Eastern and Western counties. Traditionally they are deep fired or sautéed in butter. Turkey with bacon fat as flavor additive was selected as the second test material. Both materials must be puréed in order to become extrudable. The process of puréeing food breaks the macrostructure of the material, changing the texture and taste. By adding transglutaminase to the puree right before printing, the material retains its rheological properties, but will reform a new protein matrix over time. In order to test the purees survivability, the scallop was deep fried and the turkey was cooked sous-vide.

Sous-vide is a method of cooking in which the ingredients are heated for an extended period of time in a low temperature. The food is cooked in hot water well below boiling. This helps to preserve the integrity of the ingredients. (7) Often this is done by heating the food in a vacuum sealed bag in hot water. Vacuum sealing a printed uncooked paste would destroy its shape. Instead, the printed constructs were cooked in 100% humid environments using a controlled vapor (CVap) oven. In a CVap oven a water basin and air cavity are connected but have independent temperature controls. Varying the temperatures can control for humidity and cooking temperature in the air cavity where the food is placed. (8)

Agar was examined as a food additive for creating printable vegetables. Agar, derived from red algae, has been used as an ingredient in desserts in eastern countries. Vegetarians often use it as a substitute for gelatin in western cuisine. It is used widely in modern cooking techniques due to its shear-thinning properties. (9) A celery fluid gel was created by pureeing celery and adding agar powder to allow it to reconstitute. Test of printability were done using a Fab@Home 3d printer.

Results: Modified Traditional Recipes

A printable and thermally stable cookie recipe can be made as follows provided the ratio of ingredients is maintained. The test recipe ingredients and instructions are listed in table 1. The batter should be mixed vigorously between steps. Once the batter is made, it is humidity dependant and should be used immediately for best results. The printed cookies should be chilled in a freezer following extrusion to ensure geometric stability. Once chilled, the cookies should be baked at 250 degrees Celsius until the browned.

Ingredient	Amount	Instructions
Unsalted Butter	220g	1) Mix the butter until fluffy. 2) Add powdered sugar in small doses of no more than 20g. 3) Add egg yolks one at a time 4) Add flavor and color additives. 5) Add flour in 6.6g bathes until desire consistency is reached.
Powdered Sugar	110g	
Egg Yolk	3	
flour	330g	

Table 1: Recipe for thermally stable printable sugar cookies.

As a test of the geometric fidelity of the recipe, a complex cookie was printed. The exterior of the cookie was chosen to be a prism in order to allow for accurate visual inspection of the geometry before and after cooking. The interior of the cookie was a capital C, made of a chocolate version of the recipe. Coco powder added to the recipe changed the batters color.

The cookie was printed using a Fab@Home model 2 with a duel syringe displacement tool. Air entrapped in the syringes used during printing caused the material to be very compressible during printing. Inaccuracies in the printer calibration, resulting from the entrapped air, caused material to flow excessively (chocolate dough in figure 2a). The exterior of the cookie did slump, causing the base of the cookie to be wider than the top. Despite the printing errors and exterior slumping, the interior of the cookie retained its shape.

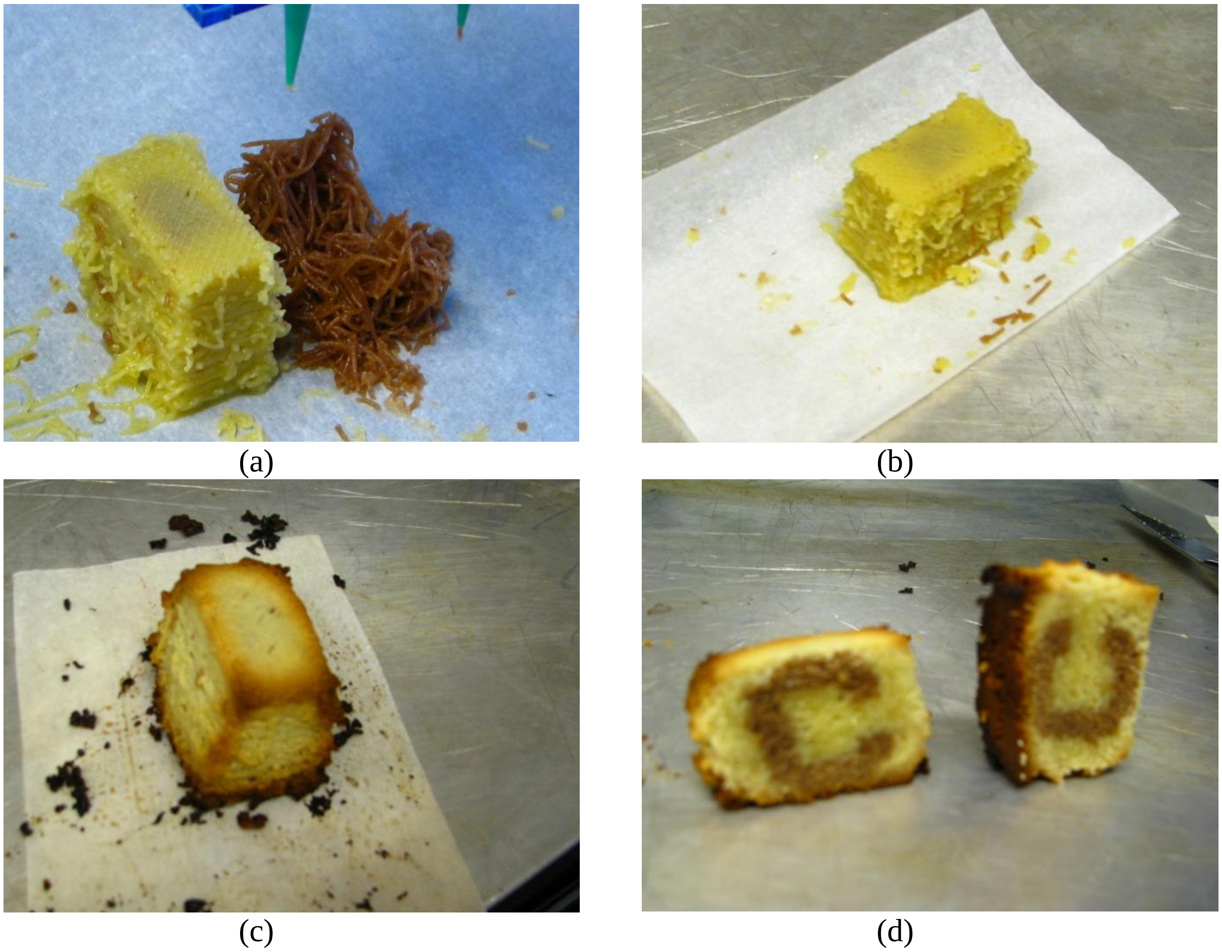
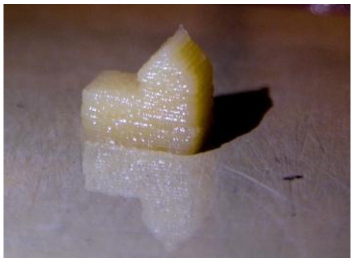


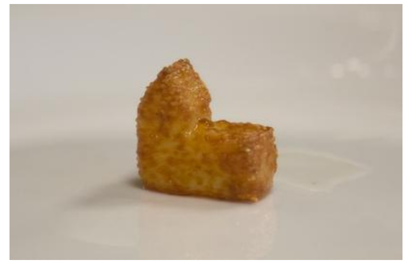
Figure 2: A prism shaped cookie with and embedded extruded C shaped was printed using a Fab@Home (a) . The cookie was chilled to stabilize the geometry (b) and then baked(c). While the exterior slumped slightly(c), the interior geometry was preserved.(d)

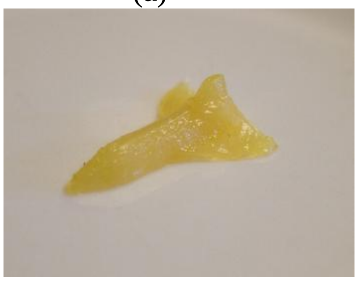
Results: Additives

In order to test the scallop, two geometries were deep fried, a truncated L, and a space shuttle. These shapes demonstrate the materials ability to retain curves, edges and vertical surfaces during and after deep frying. Only extremely thin sections of the space shuttle wings deformed significantly due to deep frying. (Figure 3). The Turkey with transglutaminase was printed into a truncated dome. The turkey was successfully cooked using sous-vide methods. The process of cooking caused the turkey to contract inwards, making the object smaller, and causing the center to bow upwards (Figure 4). Expert chefs consumed the printed meats to ensure it had the proper taste and texture. Both materials passed examination by the chefs.

The Celery fluid gel was extrudable, and could be extruded into thin shapes. The fluid gel however was not able to hold a complex three-dimensional shape. In order to test the properties of the gel further, a cube of it was printed inside of a turkey cube construct.


(a)


(b)

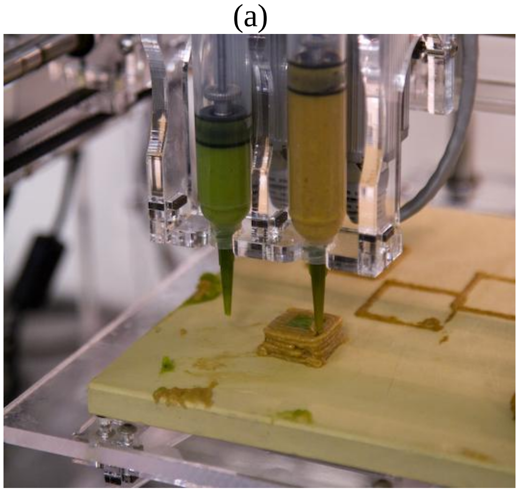

(c)


(d)

Figure 3: Two test geometries were printed, a truncated L(a) and a space shuttle(c). Both shapes were deep fried and retained most of their shape(b)(d), only thin regios deformed due to deep frying (d).


(a)


(b)


(c)

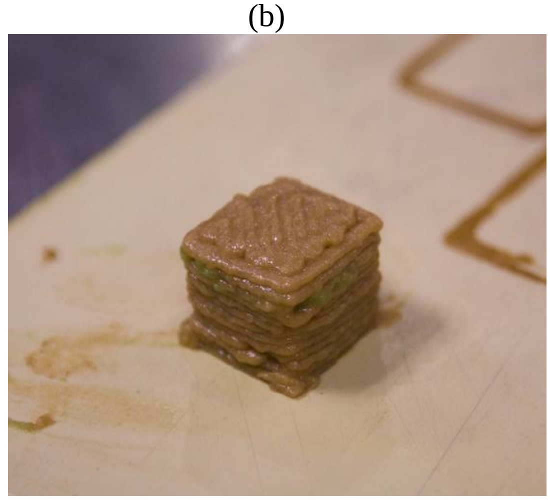

(d)

Figure 4: Turkey with transglutaminase was printed into a truncated hemisphere(a) and cooked sous-vide(b). The overall shape survived cooking, but the meat did contract inwards causing it to bow. Celery fluid gel (green fluid in c) was printed into a turkey cube (d).

Discussion and Conclusion:

Using simple additives and modifications of traditional recipes it is possible to create complex geometries which can be cooked like ordinary food. Transglutaminase allows meats to be directly 3d printed for the first time, widening the scope of solid freeform fabrication of food. Novel formulations of recipes allow for complex shapes to be embedded in traditional foods such as cookies.

People are excited to have SFF solve culinary problems and allow new design spaces for food. These processes may allow for complex material behaviors in cooked dishes. Just as Objet machines can have material gradients to produce various material strengths, material gradients in food may allow novel textures and tastes. (10) The key barriers to SFF's adoptance in the culinary relm are the physical limitation of the material sets printing requires and printers use, and the integration of SFF'ed food with traditional cooking techniques. The work presented here solves the second issue by demonstrating that SFF'ed food can be prepared like traditional cuisine.

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