

**Influence of Hydroponically Grown Hoyt Soybeans and Radiation  
Encountered on Mars Missions on the Yield and Quality of Soymilk and  
Tofu**

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## ABSTRACT

Soybeans were chosen for lunar and planetary missions due to their nutritive value and ability to produce oil and protein for further food applications. However, soybeans must be processed into foods prior to crew consumption. Wilson et al. (2003) raised questions about (1) the influence of radiation (on germination and functional properties) that the soybeans would be exposed to during bulk storage for a Mars mission, and (2) the impact of using hydroponically grown versus field grown soybeans on the yield and quality of soyfoods. The influence of radiation can be broken down into two components: (A) affect of surface pasteurization to ensure the astronauts safety from food-borne illnesses (a Hazard Analysis Critical Control Point), and (B) affect of the amount of radiation the soybeans receive during a Mars mission. Decreases in the amount of natural antioxidants and free radical formation and oxidation induced changes in the soybean (lipid, protein, etc.) will influence the nutritional value, texture, quality, and safety of soyfoods made from them. The objectives of this project are to (1) evaluate the influence of gamma and electron beam radiation on bulk soybeans (HACCP, CCP) on the microbial load, germination, ease of processing, and quality of soymilk and tofu; (2) provide scale up and mass balance data for Advanced Life Support subsystems including Biomass, Solid Waste Processing, and Water Recovery Systems; and (3) to compare Hoyt field grown to hydroponically grown Hoyt soybeans for soymilk and tofu production. The soybean cultivar Hoyt, a small standing, high protein cultivar that could grow hydroponically in the AIMS facility on Mars) was evaluated for the production of soymilk and tofu. The quality and yield of the soymilk and tofu from hydroponic Hoyt, was compared to Vinton 81 (a soyfood industry standard), field Hoyt, IA 2032LS (lipoxygenase-free), and Proto (high protein and antioxidant potential). Soymilk and tofu were produced using the Japanese method. The soymilk was coagulated with calcium sulfate dihydrate. Soybeans and tofu were evaluated using chemical, microbial, and instrumental sensory methods. The surface radiation of whole dry soybeans using electron beam or gamma rays at 10 or 30 kGy did provide microbial safety for the astronauts. However, these doses caused oxidative changes that resulted in tofu with rancid aroma, darkening of the tofu, lower tofu yields, more solid waste, and loss of the ability of the seeds to germinate. While lower doses may reduce these problems, we lose the ability to insure microbial safety (cross-contamination) of bulk soybeans for the astronauts. Counter measures could include vacuum packaging, radiating under freezing conditions. A No Effect Dose for food quality, below 10 kGy needs to be determined. Better estimates of the radiation that the food will be exposed to need to be determined and shared. Appropriate shielding for the food as well as the astronauts needs to be developed. The Hoyt soybean did not provide a high yielding, high quality tofu. A new small scale system for evaluating soybeans was developed using 50 g quantities of soybeans.

## INTRODUCTION

Soybeans were chosen for lunar and planetary missions due to their nutritive value and ability to produce oil and protein for further food applications. However, soybeans must be processed into foods prior to crew consumption. Wilson et al. (2003) raised questions about (1) the influence of radiation (on germination and functional properties) that the soybeans would be exposed to during bulk storage for a Mars mission, and (2) the impact of using hydroponically grown versus field grown soybeans on the yield and quality of soyfoods. The influence of radiation can be broken down into two components: (A) affect of surface pasteurization to ensure the astronauts safety from food-borne illnesses (a Hazard Analysis Critical Control Point), and (B) affect of the amount of radiation the soybeans receive during a Mars mission. Decreases in the amount of natural antioxidants and free radical formation and oxidation induced changes in the soybean (lipid, protein, etc.) will influence the nutritional value, texture, quality, and safety of soyfoods made from them. The NASA Advanced Food Technology team needs to evaluate small quantities of hydroponically grown soybeans to determine their acceptability for Lunar and Mars missions. In addition, due to limited quantities of soybeans, it is necessary to develop a methodology for evaluation of smaller quantities of soybeans. Due to the fact that the exact dose the astronauts and foods would be exposed to during a Mars mission was not available from NASA, we concentrated on the use of radiation as a HACCP step to insure that the bulk soybeans would not be vectors for food-borne illness microorganisms. Both e-beam and gamma radiation were used as a CCP to insure the safety of the astronauts. While radiation can be used to pasteurize and sterilize foods, the radiation can influence the sensory and nutritive value of the food.

### *Radiation and Food Systems*

Irradiation is one of the approved methods to extend the shelf life, and preserve foods. Less than one kGy can be used to inhibit sprouting of potatoes, control insects in fruits and grains, and delay ripening. 1-10 kGy treatments can kill pathogenic microorganisms, whereas 30kGy to 67 kGy can be used to sterilize foods (meats, dried spices, etc.) (Bennion and Scheule, 2004; Potter and Hotchkiss, 1995).

Ionizing radiation is a primary concern not only for human health but also for food quality and functionality. The foods shipped to Mars must be free from food-borne illness microorganisms and pathogens. An extended inter-planetary mission to Mars, as proposed by NASA, will require a 5-year shelf life for prepackaged foods for the return flight. In addition, any ingredients or food items used on the planetary surface will require a shelf life of close to 5 years. Understanding the effects of safety measures taken prior to transit, as well as adverse conditions to which these products will be exposed, is necessary to enable development of a high quality nutritious food system.

**Lipid Oxidation:** The basic components of food consist of water, carbohydrates, proteins, lipids, vitamins, and minerals. Lipids may be the most affected by radiation because free radicals will participate in the initiation step of the lipid oxidation reaction. This oxidative process consists of three steps (initiation, propagation, and termination) and leads to the development of short chain acids, aldehydes, ketones, carbonyls, and

peroxides that may impart off-odors and off-flavors in lipids and foods containing lipids. Even small amounts of these compounds may leave foods, oils or fats unfit for consumption. Unsaturated fatty acids (containing double bonds) and other unsaturated compounds in foods are easily oxidized, which may make soybeans (high in unsaturated fatty acids (oleic, linoleic and linolenic acids) very susceptible to this type of preservation technique. High Temperatures, presence of oxygen, iron, and UV light are all known to catalyze the formation of free radicals and the ensuing autoxidation. The task of keeping foods from becoming oxidized is not an easy task. High barrier opaque packaging, use of vacuum packaging, and the addition of chelating agents (EDTA) and antioxidants (natural Vitamin E and C; synthetic BHA, BHT, TBHQ) are currently used to slow these oxidation reactions. While soybeans contain Vitamin E, it will be 'used up' protecting the unsaturated fatty acids, thus allowing oxidation to start after the initial lag phase in this reaction.

**Radiation effects on soybeans:** Radiation has been used to create mutagens to develop new soybean oil cultivars. Hammond and Fehr (1975) used X-rays and ethyl methylsulfonate to create cultivars with low linolenic acid content. Seeds from parent strains, F<sub>2</sub> seeds, and crosses were irradiated (X-ray) at levels of 10, 15, 20, and 25 Kr. While seeds treated with 20 and 25 Kr had a poor germination rate, the 10 Kr gave near normal germination.

Wilson during his NASA Faculty Fellow Program (NFFP) in 2003 at Johnson Space Center (Houston, TX) raised questions about the influence of radiation (on germination and functional properties) that the soybeans would be exposed to during bulk storage prior to and during a Mars mission. The influence of radiation can be broken down into two components: the affect of surface pasteurization to ensure the astronauts safety from food-borne illnesses (HACCP, CCP), and the affect of the amount of radiation the soybeans receive during a Mars mission.

### ***Hydroponic Soybeans on Mars***

It has been proposed that astronauts on extended duration missions might hydroponically grow their own soybeans for production. Specifically, NASA has chosen the Hoyt variety of soybean for its short full-grown stature and relatively high protein count. Research has shown (Watanabe, T., et al. 1964; Wilson, 83, 85, 86, 04) that differences in soybeans will have an effect on the sensory characteristics of soy products. As such, there was a need to evaluate the composition of the HOYT soybeans, their ability to imbibe water, and their protein extractability for tofu manufacture, in order for the astronauts to produce food from the soybeans. All tofu-making processes have a set of steps necessary to produce acceptable products. Although minor changes can be made depending on the technique used and the desired type of tofu (firm or silken style), all processes involve: soaking of dry beans, grinding the hydrated beans, pasteurization, filtering solids out of the soymilk, coagulation, and pressing. Soybeans must be evaluated for their ability to produce acceptable products with maximum yields and minimum waste streams. During Wilson's 2003 NFFP at JSC, no hydroponically grown soybeans were available. However, the field grown Hoyt soybeans were found to be of

poor quality and that they produced inferior soymilk and tofu (compared to Vinton 81 and IA 2032LS cultivars). The Hoyt cultivar had less protein in the bean and resulting tofu than all of the other cultivars. The tofu and okara were an unacceptable gray/black mottled color compared to the cream colored Vinton 81 standard. The IA 2032 LS cultivar is a lipoxygenase- free (lacks the enzymes that catalyze lipid oxidation) that had a much milder aroma and flavor, than the other cultivars evaluated in this study.

Therefore, the objectives of this research was to (1) determine the influence of radiation (pasteurization and sterilization), as a HACCP, CCP step, on the germination rate and the quality of tofu; (2) to compare Hoyt field grown to hydroponically grown Hoyt soybeans for soymilk and tofu production, (3) provide scale up/down procedure to evaluate small quantities of soybeans for food use, and (4) supply additional mass balance data for Advanced Life Support subsystems including Biomass, Solid Waste Processing, and Water Recovery Systems.

**Research Approach:** Soybean cultivars were selected based upon the results of my 2003 NFFP (Vinton 81 and IA 2032LS), the availability of hydroponic and field grown Hoyt soybeans, and the availability of a high antioxidant capacity Proto soybean. All of the cultivars selected were non-GMO, which were grown at known locations. Vinton 81 is a high protein, large seeded cultivar that is considered the gold standard by the Soyfoods Industry around the world. It is used for soymilk and tofu production. IA 2032LS is a large seeded, high protein cultivar that is lacking all three lipoxygenase isoenzymes. Lipoxygenase enzymes catalyze the formation of hydroperoxides that break down unsaturated fatty acids into low molecular weight flavor compounds, described as green, grassy, beany, painty, oxidized odors and flavors. All soybeans were stored in the dark at 20 C prior to and after irradiation

One pound of each cultivar was put into a large ziploc bag, the air squeezed out, sealed, and labeled prior to being treated. The amount in the bag allowed a single layer of seeds to be exposed to the radiation treatment. The bagged soybeans were irradiated at 5 doses (0, 10, 20 kGrays) at the Iowa State University Linear Accelerator Facility, Texas A&M Electron Beam Facility for e-beam and the University of Illinois for gamma irradiation (Irradiation costs were covered by grants from NASA FT CSC and USDA, CSREES Regional Research Project NC-136) . One set of each cultivar was shipped to each location, but not irradiated to serve as a control. After each treatment, the soybeans were divided into four batches: (1) for chemical analyses [proximate analyses, peroxide value, thiobarbatic acid], using standard AOCS procedures, and antioxidant potential (PhotoChem), aroma by GC (Wilson, 1998, 2004]; (2) microbial analyses (standard plate count, coliforms, Salmonella, yeasts and molds) using standard methods in the NASA Food Microbiology Lab (JSC, Houston, TX); (3) germination test (Bugbee, 2004) and (4) soymilk and tofu production.

The functionality of the soybeans was evaluated by manufacturing soymilk and tofu. The standardized methods of Johnson and Wilson (1984), Moizuddin, et al. (1999a), Moizuddin, Johnson, and Wilson (1999b); Wilson, 2003 were used. The Japanese method of soymilk production (Wilson (1995) from whole soybeans was utilized (soak beans 8-12 hours, grind beans, cook at 95 °C for 7 minutes, filter out okara, coagulate the

soymilk, cut the curds to release the whey, press in tofu press, refrigerate overnight prior to chemical and instrumental tests). Three different tofu presses (Fig.1) were manufactured at ISU (funded by NASA FT CSC, 2004) to allow scale-down procedures to be developed (based upon 300 g, 100 g, and 50 g batches). In addition, two NASA large tofu presses were used (Wilson, 2003; Fig.1) An 8% soluble solids soymilk was produced and coagulated using calcium sulfate dihydrate at 85 °C. The amount of coagulant needed was determined by the method of Moizuddin, Johnson, and Wilson (1999b). Yields of soymilk, tofu, okara, and whey along with the color, texture, and aroma of the soymilk and tofu were determined utilizing instrumental methods. Color was measured by using a Hunter Color Difference Meter Model XE under D65 light with a 10-degree standard observer. Texture was determined by using a Texture Profile Analysis (TPA) procedure (Bourne, 1978) to determine hardness, brittleness, adhesiveness, cohesiveness, and elasticity of each sample. A 1 cm-cube of tofu was compressed (80%) using a compression head in a Texture Technology TA XT2ci instrument. pH and conductance measurement of the whey were used to determine the optimum coagulation of the milk (Moizuddin, Johnson, and Wilson, 1999b; Wilson, 2003). All procedures were replicated in triplicate. The results were analyzed statistically for treatment affects, and correlations.

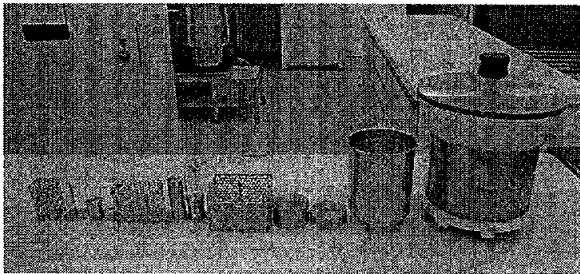


FIGURE 1. TOFU PRESS BOXES. THE TWO PRESSES ON THE RIGHT WERE USED IN NFFP 2003. THE FOUR PRESSES ON THE LEFT WERE USED FOR THIS STUDY.

### ***Results and Discussion***

While awaiting the arrival of the tofu presses and the irradiated soybeans, two major activities were initiated. Dr. Juming Tang and I prepared a White paper on the retortable pouch thermal processing system used by the NASA ISS product development team. Action was taken based upon the recommendations given in this report. The second activity used Vinton 81 and Hoyt soybeans from my NFFP 2003 to standardize new calcium sulfate dihydrate and to teach an intern how to manufacture soymilk and tofu.

To optimize the processing of soybeans using the new tofu presses and the evaluation of the irradiated soybeans, a preliminary characterization of the chosen soybean varieties was necessary. The preliminary data using Hoyt, Vinton 81, and IA 2032LS soybeans from NFFP03 were used to evaluate the new soymilk and tofu manufacturing system. Likewise, these soybeans were used to scale down the amounts of soybeans needed per test from 3,000 g to 50 g batches. After the arrival of the irradiated soybeans, control and treated samples were run in order to get an estimate of their

behavior and the amount of coagulate needed per treatment. This preliminary data yielded information about the characteristics of the beans themselves as well as how they performed in soymilk, tofu, okara, and whey processing. The initial processing was done in small batches on the stove in the Space Food Systems Laboratory to allow for manipulation of a number of variables at once, and to maximize the used of the limited supply of hydroponic Hoyt soybeans (300 g).

Upon the completion of the preliminary experiments, an optimal processing technique was developed for the Hoyt beans and the irradiated soybeans using 50 g batches. Additional tests were performed using a jacketed kettle in the food lab to verify conditions on a larger scale. Results were compared to NFFP 2003 and to commercial ISU Pilot Plant data.

With scale-ups and base-line data obtained, the main experiment with replication was initiated.

***Preliminary Hoyt soybean characterization and process optimization***

Hoyt soybeans were selected by NASA because they are believed to be high in protein, low growing, and can be grown hydroponically. Hoyt beans contain black hilum and seed coat staining in NFFP03 and both field and hydroponically grown crops this year had the same characteristics. In both years, this stain was carried into the soymilk and tofu (Wilson, 2003). Only a limited amount of the Hoyt soybeans grown under hydroponic conditions was available (300 g), so 50 g batches were used in the scale-up and in final evaluations of all treatments. Addition hydroponically grown soybeans should be grown and evaluated in the future due to the small sample size available this year, Compositional data for all the cultivars are given in Table 1.

**Table 1. Soybean Composition**

	Sample	Moisture	13% moisture basis		
			Protein	Oil	Fiber
2002	Vinton 81	8.9	38.4	17.4	4.6
	IA 2032 LS	10.8	39.0	18.2	4.6
	Proto	9.4	38.2	16.9	4.7
2003	Vinton 81	7.9	39.3	18.2	4.6
	IA 2032 LS	7.8	37.6	20.2	4.5
	Proto	9.0	39.6	16.0	4.7
JSC	Hoyt-F	9.6	36.2	18.4	5.1
Utah	Hoyt-F	10.8	37.5	17.2	4.8
ISU	Hoyt-F	9.0	36.3	19.1	4.6
ISU	Hoyt-H	10.0	32.0	na	na

The protein content of traditional soybean cultivars ranged from 37.6 to 39.6% at 13% moisture. The field grown Hoyt ranged from 36.2-37.5%, whereas the hydroponically grown Hoyt was only 3 (Table 1). In general the Hoyt cultivar was lower in protein, slightly higher in fiber, and similar in oil content. (Table 1). This compositional data was compared to three other cultivars: Vinton 81, the soyfoods industry 'gold standard' high protein and seed size; IA 2032LS, a high protein, large

seeded lipoxygenase free (low beany flavor, non-GMO) cultivar; and Proto, a high protein cultivar from North Dakota that is purported to have a higher anti-oxidant level. All of the food-grade cultivars were higher in protein than the Hoyt cultivars. Figure 2 demonstrates the higher antioxidant capacity of the Proto cultivar based upon PhotoChem (chemluninance) data from this study.

The new calcium sulfate dehydrate was ordered by NASA. However, it was in a small granular form rather than a powder. We ordered a new food-grade powdered from from Custom Gypsum (OK). In our evaluations it took almost twice the amount

of granular form than the powdered form to get the same degree of coagulation. Initial runs of all of the control and treated soybeans were made to determine the amount of coagulant needed, as was done in NFFP 2003. The Hoyt soybeans from NFFP 2003 still needed 0.052 N calcium sulfate dihydrate to form curds, compared to 0.023-0.025 N for the new Hoyt (Field grown and hydroponic), the cultivars from NFFP 2003, and the new crop control cultivars. The requirement for more coagulant by Hoyt from this years study, confirms our data from last year (NFFP 2003). Likewise, pH and conductivity data matched the data from last year (NFFP 2003). Amounts of needed resuppliable inputs are of concern to NASA because they would contribute to the overall mass of a mission.

Fifty, 100, and 300g batches of each cultivar were soaked and processed to evaluate the new pressing boxes for their ability to scale up or scale down a process. The 300g press worked well and scaled up to the kettle and pilot plant systems. The 100 and 50g were harder to use due to the thinner diameter and higher height. The 50 g tofu box gave consistently higher yields, due to less efficient pressing, even with the same force/area<sup>2</sup>. Due to the small quality of hydroponic beans, the 50 g press box was used. All color and two cubes of tofu/press box were available from each 50 g batch. The hydroponically grown Hoyt soybeans absorbed less water than the field grown Hoyts during the soaking step (Table 2). This was due to the presence (14%) of “stone” or “hardshell” beans. These beans did not rehydrate, even after 24 hours of soaking. There were no differences in the amount of okara or yield of tofu between field and hydroponically grown beans.

Previous studies found that Hoyt beans soak up 2.3 times their weight compared to 2.38 this year for field grown and 2.22 for hydroponically grown (Tables 2 and 3). The Vinton cultivar (commonly used in the soyfoods

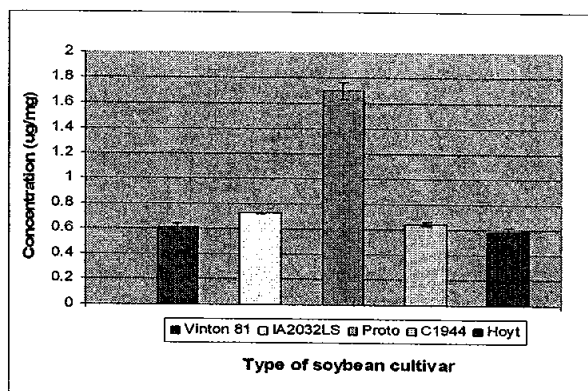


Figure 2. Antioxidant potential of five soybean cultivars.

Table 2. Comparison of Hydroponically and Field Grown Hoyt Soybeans

	FIELD	HYDROPONIC
Water Uptake	2.38*	2.22
Okara Yield	83.70	1.20
Tofu Yield	81.90	2.27



industry) is much more efficient in making tofu than the other beans. The Vinton cultivar produced tofu that was 2.63 times the dry weight of bean used.

As reported in 2003, the color of seed coat and cotyledon were carried into the soymilk and the tofu. Using the HunterLab Model XE, significant differences in the color of the tofu, okara, whey, and soymilk were found. The Hoyt soybeans from all locations and crop years produced what could be described as an unappealing grayish color soymilk, tofu and okara. The Proto cultivar produced a more tan in color tofu, due its brown hilum. The industry standard Vinton 81 and the IA 2032 LS cultivars produced a more usual creamy light yellow color soymilk, tofu and okara.

### ***Irradiation Study***

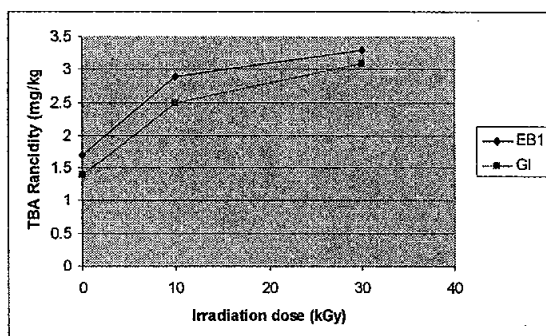
**TABLE 3. SELECT PROCESSING DATA FOR THE PROTO CULTIVAR**

Dose	Water Uptake	Okara	Tofu
0	2.37	1.38	2.20
10E	2.44	1.30	2.38
10G	2.46	1.48	2.10
030E	2.40	1.16	1.92

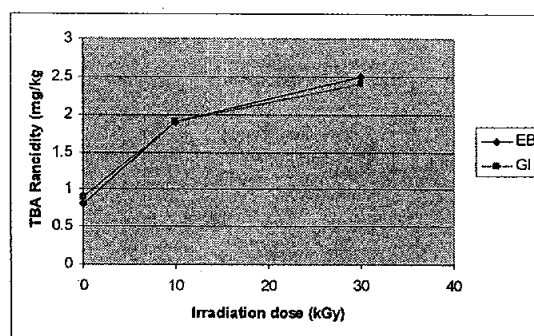
### ***Microbial Load of the Soybean Cultivars***

- All soybeans in this study would meet Shuttle Food Microbiological Requirements (They can fly!!)
- No coliforms or Salmonella were found.
- Average total aerobic counts ranged from 0 to 250 CFU/g.
- Yeasts and Molds ranged from 0 to 18 CFU/g. Aspergillus flavus was found on one sample, which may be due to contamination after irradiation (sampling).

### **TBA, A Measure of Oxidation: E-Beam and Gamma**



**FIGURE 3. TBA RANCIDITY FOR VINTON 81 AT IRRADIATION DOSES OF 0KGY, 10KGY AND 30KGY**



**FIGURE 4. TBA RANCIDITY FOR IA2032LS AT IRRADIATION DOSES OF 0KGY, 10KGY AND 30KGY.**

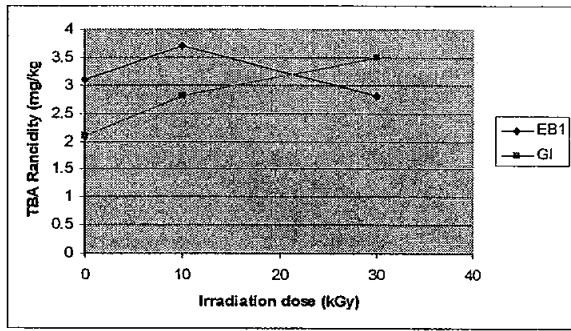


FIGURE 5. TBA RANCIDITY FOR PROTO AT IRRADIATION DOSES OF 0KGY, 10KGY AND 30KGY.

While TBA values increased with irradiation, the TBA levels were lower for the IA 2032 LS. It was also noted that this cultivar had a less rancid/oxidized odor.

### Free Fatty Acids

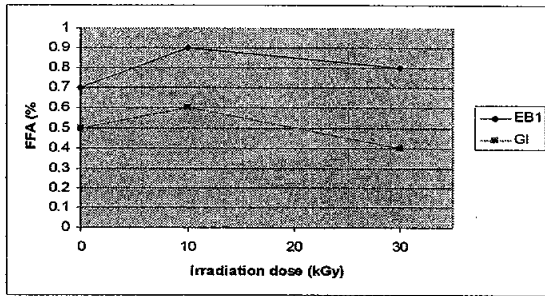


FIGURE 6. PERCENT FREE FATTY ACID (FFA) FOR VINTON 81 AT IRRADIATION DOSES OF 0KGY, 10KGY AND 30KGY

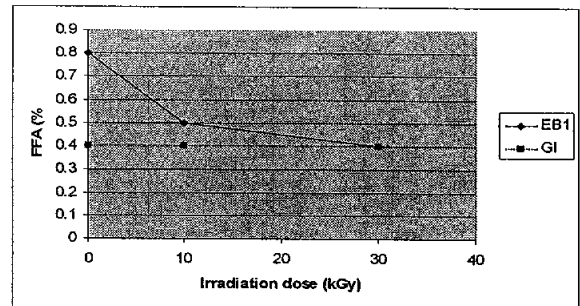


FIGURE 7. PERCENT FREE FATTY ACID (FFA) FOR IA2032LS AT IRRADIATION DOSES OF 0KGY, 10KGY AND 30KGY

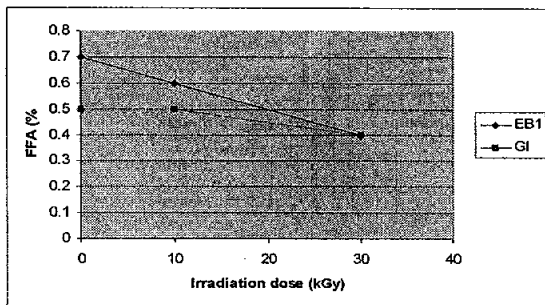


FIGURE 8. PERCENT FREE FATTY ACID (FFA) FOR PROTO AT IRRADIATION DOSES OF 0KGY, 10KGY AND 30KGY.

In general, FFA levels decreased with increasing dosage. However, Vinton 81 FFA decreased at a lower rate than the other two cultivars. Gamma radiation FFA values were lower than the E-bean at 10 kGy. The decrease in FFA may be due to the destruction of the free polyunsaturated FFA, as noted by increasing TBA and oxidized/rancid aroma values.

In addition to the changes in appearance, noted above, the soybeans

irradiated at 30 kGy had less okara (small particles passed the filtering system) and lower tofu yields (Table 3 ). The tofu also had a softer texture, more pasty.

### Appearance and Aroma of the Soaked Soybeans

- Irradiated raw soaked soybeans:
  - Were visually damaged at the ends by the treatment (electron and Gamma)
- 30 kGy caused more damage.
  - Both 10 and 30 kGy soaked beans had a rancid aroma
  - IA2032LS had less of this aroma
- The 30 kGy soybeans were softer than the other treatments.
- After grinding and during cooking, the IA2032LS beans had less rancid-oxidized aroma than the other irradiated cultivars.
- The hydroponically grown Hoyt soybeans contained ‘hardshell’ or ‘stone’ soybeans “Like a Rock” to quote an Insurance company.
- The hydroponically grown beans absorbed less water than the field grown Hoyts.
- The hardshell beans were not altered by irradiation treatments.
- The irradiated beans lost more solids into the soak water than the control beans (concern for waste water treatment)
- Control < 10 kGy < 30 kGy
- 0.2 to 4% solids lost into the soak water

### Color of the Tofu

TABLE 4. VINTON 81 AND PROTO TOFU COLOR

Cultivar	L*	a	b
<i>Vinton 81</i>			
0E	83.70	0.9	14.9
10E	81.90	1.2	13.7
30E	80.95	1.7	12.9
0G	85.91	0.8	17.6
10G	84.96	1.4	16.5
30G	82.92	1.9	16.2
<i>Proto</i>			
0*	87.82	0.8	14.9
10E	86.65	1.2	14.6
10G	85.76	1.3	15.1
30E	84.57	1.7	15.2

E= Electron G=Gamma

\* L= 0 (black) /100 (white); a-green/ + red; b-blue/ + yellow

### Color Summary

- Color from the seed coat and cotyledon were carried into the soymilk and the tofu, as reported by Wilson (NFFP 03).
- Visual and instrumental methods detected these color changes.
- Electron and gamma irradiation to obtain pasteurization or sterility reduced the lightness and yellowness, while increasing the redness (more tan color) of the soymilk and tofu (Table 4).
- These color changes occurred for all cultivars.

## Texture of the Tofu

**TABLE 5. VINTON 81 TOFU TEXTURE AS INFLUENCED BY IRRADIATION OF THE SOYBEANS**

Dose (kGy)	Hardness (kg)	Adhesiveness Kg-sec	Springiness	Cohesiveness	Resilience
<b>E-Beam</b>					
0	1.454	-0.00751	0.875	0.712	0.380
10	1.247	-0.01087	0.870	.0674	0.317
30	1.006	-0.03474	0.865	0.520	0.220
<b>Gamma</b>					
0	1.393	-0.02546	0.874	0.684	0.348
10	1.287	-0.03056	0.872	0.593	0.288
30	.0522	-0.05216	0.748	.0386	0.124

## Texture Summary

- **Irradiation of the soybeans resulted in (Table 5):**
  - Softer tofus
  - Less adhesive curds
  - Less springiness
  - Less cohesiveness
  - Less resilience
  - Lower yields
  - More okara leaking into the tofu

The comparative studies showed that the Vinton 81 soybeans were more efficient in tofu making than the Hoyt. The Vinton soybeans yielded 263% of their dry weight in tofu while the Hoyt yielded only 120% of their dry weight in tofu.

Finally, the Vinton 81 soybeans (which are standard in industry) produced better sensory qualities than the Hoyt beans. The color was more similar to commercially available tofu for the Vinton 81. Although no taste panels were conducted, it was noted that the aroma during the making of the two tofus was much more pleasant for the Vinton beans.

For these reasons, we feel that NASA should consider replacing the hydroponic Hoyt beans with Vinton 81. As an alternative to growing their own soybeans, the Vinton beans would be sent with crew as a dry ingredient. Although this would take up more space, the benefits of more abundant, high-quality finished soy product using less of a chemical input make this scenario appropriate for future research.

## CONCLUSIONS

- While the use of irradiation as a HACCP CCP will help prevent food-borne illness hazards to the crew, 10-30 KGy causes undesirable sensory, yield, and physical changes in the soymilk and tofu. This will most likely translate into altered functional properties when used as ingredients in other foods.
- Aroma, color and textural changes made unacceptable soymilk and tofu.
- The natural antioxidant level in the soybean cultivars was not sufficient to protect the soybeans from these dose levels.
- The lipoxygenase-free soybean cultivar was less oxidized, due to (Hypothesis) the lack of enzyme-substrate interaction after the radiation has, essentially, punched holes in the membranes and structural material.
- Based upon a small sample size, the hydroponically grown Hoyt behaved similarly to field grown Hoyt cultivars, with the exception of 'stone' beans.
- As noted in my NFFP2003 report, the black hilum and seed coat staining detracts from the quality of the tofu and it's okara. A clear hilum cultivar should be used.
- Counter measures could include vacuum packaging, radiating under freezing conditions.
- A No Effect Dose for food quality, below 10 kGy needs to be determined.
- Better estimates of the radiation that the food will be exposed to need to be determined and shared.
- Appropriate shielding for the food as well as the astronauts needs to be developed.
- The actual doses that the crew and food will experience during normal and solar flair transit to Mars needs to be determined (or made known).
- More hydroponically grown soybeans are needed in order to verify the finding of this study.

## Deliverables

A new small scale system for evaluating soybeans was developed using 50 g quantities of soybeans. In a separate study with Dr. Juming Tang, the retortable pouch procedures and processing system at Texas A&M were evaluated and a White paper was produced. Action was taken, based upon the recommendations from this report.

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