TECHNICAL REPORT
NATICK/TR-20/008

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EVALUATION OF A NOVEL VACUUM MICROWAVE DRYING (VMD) TECHNOLOGY FOR RATION FOOTPRINT REDUCTION

by
Tom Yang

February 2020

Final Report
June 2017-May 2018

U.S. Army Combat Capabilities Development Command Soldier Center
Natick, Massachusetts 01760-5018

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14. ABSTRACT

The US Army Natick Soldier, Research, Development, and Engineering Center (NSRDEC), now known as the U.S. Army Combat Capabilities Development Command – Soldier Center, obtained FY17 RDECOM-sponsored Foreign Technology (and Science) Assessment Support (FTAS; TIP 2633) funds. This award funds a project to evaluate a Canadian-developed, novel Vacuum Microwave Drying (VMD) system that renders food shelf stable with near-fresh quality. VMD applies vacuum and microwave to rapidly and economically dry ration components at low temperatures to reduce the weight of rations and to retain quality, nutrition, and ensure safety. It will also be used to produce partially dry food components and subsequently compress the food components using conventional compression or ultrasonic agglomeration to further reduce weight and volume (at minimum of 50%) of individual and squad-size/group sized military ration components.

15. SUBJECT TERMS

VMD	RATIONS	FRESH FOODS	COMPRESSED FOODS
TRAYS	SAMPLING	MICROWAVES	LOW TEMPERATURE
DRUMS	SHELF LIFE	SHELF STABLE	WEIGHT REDUCTION
DRYING	NUTRIENTS	GROUP RATIONS	VOLUME REDUCTION
SAFETY	NUTRITION	FOOD PROCESSING	VACUUM APPARATUS
QUALITY	COMPRESSION	FOOD COMPONENTS	

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PREFACE

The US Army Combat Capabilities Development Command – Soldier Center (CCDC-SC) obtained FY17 RDECOM-sponsored Foreign Technology (and Science) Assessment Support (FTAS; TIP 2633) funds. This award funds a project, dated June 2017 to May 2018, to evaluate a Canadian-developed, novel Vacuum Microwave Drying (VMD) system that renders food shelf stable with near-fresh quality. VMD applies vacuum and microwave to rapidly and economically dry ration components at low temperatures to reduce the weight of rations and to retain quality, nutrition, and ensure safety. It will also be used to produce partially dry food components that will be subsequently compressed using conventional compression or ultrasonic agglomeration to further reduce weight and volume (at minimum of 50%) of individual and squad-size/group sized military ration components.

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EVALUATION OF A NOVEL VACUUM MICROWAVE DRYING (VMD) TECHNOLOGY FOR RATION FOOTPRINT REDUCTION

1.0 INTRODUCTION

Background: Compact, shelf-stable, nutrient dense, eat-on-the-move ration components are the future of field feeding. Warfighters and special forces operating in all terrains and environments need to be supplied with a nutrient dense, low weight, low volume rations that will optimize combat effectiveness and improve warfighter performance and lethality by maximizing ration consumption, improving maneuverability and increasing survivability. The Combat Feeding Directorate (CFD) of the US Army Combat Capabilities Development Command – Soldier Center (CCDC-SC) has explored novel drying and compression technologies via Foreign Technology (and Science) Assessment Support (FTAS) and Small Business Innovation Research (SBIR) programs respectively, but knowledge of the effect and the extent of these technologies on the critical properties of the final product is needed. Specific processing parameters for foods vary based on the food's moisture and fat content, and need to be defined in order to properly develop components for Close Combat Assault Ration (CCAR) or a potential replacement for some Meal-ready-to-Eat (MRE), First Strike Ration (FSR), Ration Cold Weather (RCW), and Unitized Group Ration- Marine (UGR-M) components. The development and exploitation of these novel technologies will enable assured resupply in expeditionary environments, as these components will be compact enough to provide sustainment for 7 days without resupply. The knowledge obtained from this research will be valuable to expedite the product development of the CCAR and expand the variety and quality of ration components to meet these critical needs.

***Overview*:**

Impacts on:

- Combat Feeding Research and Engineering Program
- Army Warfighting Challenge: Adapt the Institutional Army
- Army Modernization Challenges relating to Soldier Lethality:
  - Ease overburdened Soldiers in Small Units
  - Reduce logistic burden of storing, transporting, distributing and retrograde of materials
  - Achieve operational maneuverability in all environments and at high operational tempo
  - Improve operational energy
  - Reduce lifecycle cost of future Army capabilities

Description:

The objective of this project was to test a Canadian-developed, innovative Vacuum Microwave Drying (VMD) system that renders food shelf stable with near-fresh quality. VMD applies vacuum and microwave to rapidly and economically dry ration components using low temperatures (< 50 ºC) to reduce the weight of rations and to retain quality, nutrition, and ensure safety (Cao et al., 2017; Zhang et al., 2017; Kumar et al., 2016; Rattanadecho and Makul, 2016; Zielinska et al., 2016; Monteiro et al., 2015; Wray and Ramaswamy, 2015; Li et al., 2011; Zhang et al., 2010; Cui et al., 2008; Cui et al., 2004; Sunjka et al., 2004; Yangyang et al., 2004; Cui et

al., 2003; Mousa and Farid, 2002; Gunasekaran, 1999; Krokida and Maroulis, 1999; Kiranoudis et al., 1997).

Some of the industrial VMD dried samples are shown in Figure 1.

Figure 1. EnWave's VMD dried samples.

An additional concept was to partially dry the food components to render them pliable such that they could be subsequently compressed to further reduce weight and volume (at minimum of 50%) for individual and squad-sized/group-sized military ration components. It's also conceptualized that the VMD semi-dried food components will have a more uniform final moisture distribution in the finished products due to a volumetric heating of microwave to flush out the moisture simultaneously throughout the food components. The uniform moisture distribution in the semi-moist food components is critical to its quality and microbial safety.

Scope of work of FTAS project:

A service contract (W911QY-17-P-0169) was awarded to EnWave Corporation (Vancouver B.C., Canada V6C 1A5) on May 23, 2017. The contract work included:

a. General Requirements:
   (1) To prepare a range of intermediate moisture food products using lab and pilot scale vacuum microwave dryers.
   (2) To conduct trials to prepare the product as close as possible to the requestor's requirements.
b. Specific Requirements:

The product shall be dried to the target moisture, packed in high barrier plastic pouches with oxygen scavenger packs and sent to the client for evaluation. Activities will include product preparation, initial moisture testing, VMD drying, final moisture testing, and packaging in a sanitary condition. Products to be prepared are: (1) whole egg-based chewy snack products; (2) meat-based chewy snack products; (3) dairy-based chewy snack products (4) fruit/veggie-based chewy snack products.

2.0 MATERIALS AND METHODS

The PI was on-site in June and October 2017 to supervise the contract work at EnWave Corp. The VMD equipment used were a 2-kilowatt (KW) lab scale NutraREV^{TM} dryer (E019; Figure 2) and/or a 10-KW pilot scale QuantaREV^{TM} dryer (E040; Figure 3a-c); the 2 KW unit was for small quantity, robust material to be dried in a rotational drum (shown below), and the 10 KW unit had exchangeable drying mechanisms for robust material (rotation drum) and delicate material (carousel trays; shown below)

2.1 VMD Equipment at EnWave Corp.

Figure 2. EnWave's 2 KW VMD system (E019; in the background of PI) uses rotation drum for drying

Figure 3a.

Figure 3b.

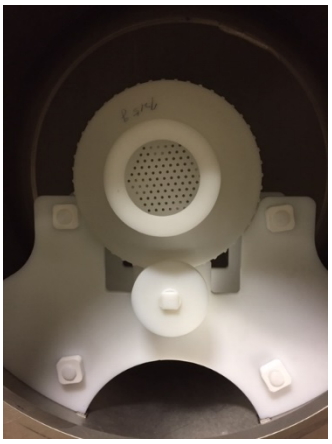

Figure 3c

Figure 3a-c. a: 10-KW pilot scale VMD system (E040); b: Rotational drying drum; c: carousel drying trays

2.2 Food products tested:

Dairy products (>50 lb delivered): natural cheese (Monterey Jack, pepper Jack, other flavored Monterey Jack, Cheddar), macaroni and cheese, pizza snacks, and cheesecake.

Meat products (>50 lb delivered): Polish Sausage, chicken and apple/pineapple sausage, chicken breakfast sausage, Italian meatball, summer sausage, taco beef, BBQ beef, ham, breakfast sausage patty, turkey, chicken and cilantro wonton, Italian meatball, teriyaki turkey, hotdog, and turkey with gravy.

Egg products (>50 lb delivered): scrambled egg, mini quiche, western omelet, cheese omelet, garden vegetable omelet, French toast, and tamago (a Japanese-style egg patty).

Fruit/vegetable products (>20 lb delivered): blueberries, blackberries, mandarin orange segments, strawberry halves, chewy banana chunks, Thai chili pepper, spinach, and mixed vegetables with salad dressing.

Appendix A contains illustrations of starting material and drying in E019 or E040.

2.3 Processing and Packaging Protocols:

For those high water content raw materials such as fruits and vegetables, an air drying (at 60-80 °C) was first used to remove excess moisture (e.g. 84% to 45% for blueberries), and subsequently VMD dried to 8% with a water activity (Aw) of 0.5 for shelf stability and compressibility. A critical temperature of 50 °C was set for the products during the VMD process; if at any time the product temperature, detected by an infrared temperature sensor, reached 50 °C, the microwave power would be shut off to avoid overheating. Examples of drying protocols are illustrated below, and photos of the finished, compressed samples are shown in Appendix B.

Process method of VMD products:

1. Determine the original weight W_0 (Kg; with or without prior air drying) and the moisture content M_0 (%)
2. Calculate the original % solid (S_0): 100- M0
3. Determine the final moisture desired: Mf
4. Calculate the final % solid (Sf) = 100 - Mf
5. Target Weight (Wf) = W_0 x S_0/Sf
6. For total dry: Weight loss (W_L) = W_0 - Wf
7. For smaller batch (~0.5 Kg), use total microwave ~ 1 Kw; for bigger batch (~3.5 Kg) use total microwave ~ 7 Kw

** For higher moisture material, start with lower total MW power and vice versa. (per EnWave)

8. Drying rate (DR) used: ~0.8 – 1 kg/TE; where TE (Total Energy; Kwh) = W_L/ DR
9. Determine the TE distribution to different MW power (bigger TE portion to start with higher MW Kw): TE1/MW1 = Time (t1; hour); TE2/MW2 = Time (t2; hour); … TE1 + TE 2 + … = TE
10. Set the MW power (kW) and time (in seconds) in the program

Example:

1. W0 of Grape Tomato = 4.75 Kg; M_0 = 92%
2. S_0 = 8%; after air drying (180 °F/2 h), the weight = 0.995Kg; therefore S_0 of air dried = 4.75 x 0.08/0.995 = 38 %
3. E.g. Desired final moisture: 8%; so the Wf = 4.75 x 0.08/0.92= 0.413 Kg
4. W_L = 0.995 – 0.413 = 0.578 Kg
5. DR = 0.75 Kg/kWh
6. TE = 0.578 /0.75 = 0.77 Kwh
7. Choose 2 Kw and 1 Kw MW power (since the original weight is 0.995 Kg)
8. TE1 = 0.4; TE2 = 0.37 therefore, t1 = 0.4/2 = 0.2 h = 720 seconds
   t 2 = 0.37/1 = 0.37 h = 1332 seconds

The dried products were packaged in high moisture and oxygen barrier film pouches with a nitrogen gas flush before shipping to Natick for evaluation and further compression tests.

2.4 Analytical analysis:
The initial moisture content, final moisture content, final water activities, and pH were determined for each product. All products underwent microbial testing (E. coli/coliform, APC, yeast and mold, and Staph) after drying and compression to verify safety.

3.0 Results and Discussions

All the samples were successfully produced either by the 2 KW (tumbling mechanism) or 10 KW (tumbling or tray) system (all processing parameters and product characteristics are shown in Appendix).

All the samples and the subsequently compressed bars were proven microbially safe. Example of microbial test results is shown in Figure 4. The rest are shown in Appendix C.

Microbiological Analytical Laboratory Report

Food Protection and Inovative Packaging Team

Microbiological Testing POC	Patrick Marek, Research Microbiologist
POC Contact	patrick.j.marek4.civ@mail.mil
	508 233 6049
Product Name	Microwave assisted drying products
Requestor	T. Yang
Date received	
Package Type	MRE foil w/vac
Sample incubation	10 days at 37
Lot number(s)	

	Item description	ID	PH	AW	Ecoli / Coliforms	APC	Yeast and Mold	Staph
1	Blackberry	BB1	3.2	0.7629	<10	50	100	<10
2		BB2	3.15	0.7616	<10	50	50	<10
3	Bacon cheddar cheese	BCC1	5.26	0.5783	<10	20	<10	<10
4		BCC2	5.34	0.5859	<10	50	<10	<10
5	M. Jack	MJ1	5.19	0.7665	<10	10	<10	<10
6		MJ2	5.18	0.7732	<10	<10	<10	<10
7	Pepper Jack	PJ1	5.24	0.6247	<10	<10	<10	<10
8		PJ2	5.25	0.6325	<10	15	<10	<10
9	Orange Mandarin	OM1	3.72	0.5157	<10	10	50	<10
10		OM2	3.77	0.5113	<10	10	100	<10
11	Jalapeno Jack	JJ1	5.09	0.6004	<10	200	10	<10
12		JJ2	5.18	0.601	<10	200	<10	<10
13	Siracha Pepper Jack	SPJ1	4.96	0.678	<10	200	175	<10
14		SPJ2	4.88	0.6119	<10	300	40	<10
15	Italian Herb Cheddar	IHC1	5.26	0.6187	<10	200	55	<10
16		IHC2	5.24	0.6187	<10	500	30	<10
17	Cheddar Cheese	CC1	5.32	0.6532	<10	10	<10	<10
18		CC2	5.27	0.6458	<10	10	<10	<10

Special Instructions: Plate counts are provide in colony forming units (CFU's) per gram or milliter of sample; Limit of Detection is 10 CFU/g or ml ; TNTC= Too numerous to count; Results of these tests apply to above samples and the coresponding production

Comments: 1. Profucts are safe for consumption

Figure 4. Microbiological test of representative VMD components.

The VMD technology was determined to be suitable for rapid full and partial removal of moisture from a wide range of food products to yield shelf stable, safe, ready-to-eat, compressible materials with organoleptically acceptable textures and flavors. The excellent color, flavor and nutrient retention properties of the developed products will enable considerable expansion of new ration components to the MRE and other feeding platforms for the Army, such as the conceptual CCAR. CCDC-SC Combat Feeding Directorate purchased a 10 KW VMD system to pursue a systematic research effort to optimally produce varieties of ration components that are calorie and nutrient dense, microbially safe, shelf stable, have a near fresh quality with significant weight and volume reduction.

4.0 Conclusions and Transition

1. The project officer visited the contractor's site on October 25-28 of 2017 and conducted various trials using the VMD system. All trials were extremely successful:

a. The concept of producing semi-moist, shelf stable products was validated successfully

b. The REV system was able to dry almost all food products without sacrificing quality and nutrients.

c. The drying process proceeded in such a short time (mostly under 60 min), indicating that this is an energy efficient process that could result in significant cost-savings.

d. The dried products, with a minimum 50% weight reduction, were easily compressed, resulting in a 2-3 fold volume reduction.

2. **Transition:**

a. Explore funding to purchase a 10 KW VMD system for ration product development for immediate field implementation of low weight, low volume, shelf stable, high quality, and nutritious ration bars. The 10 KW system, priced at $190K, is versatile for small to large sized samples and the design of the system closely resembles the industrial-scale VMD system (which will reduce the technical barriers for transition from pilot plant to actual production).

b. Conduct series of future in-house analyses to compare the nutrient retention, energy efficiency, cost reduction, packaging innovation, optimal compression, and new product development using the VMD system.

3. **Future concepts:** Variety of fresh-like entrée bars for soldiers in the field (Figure 5).

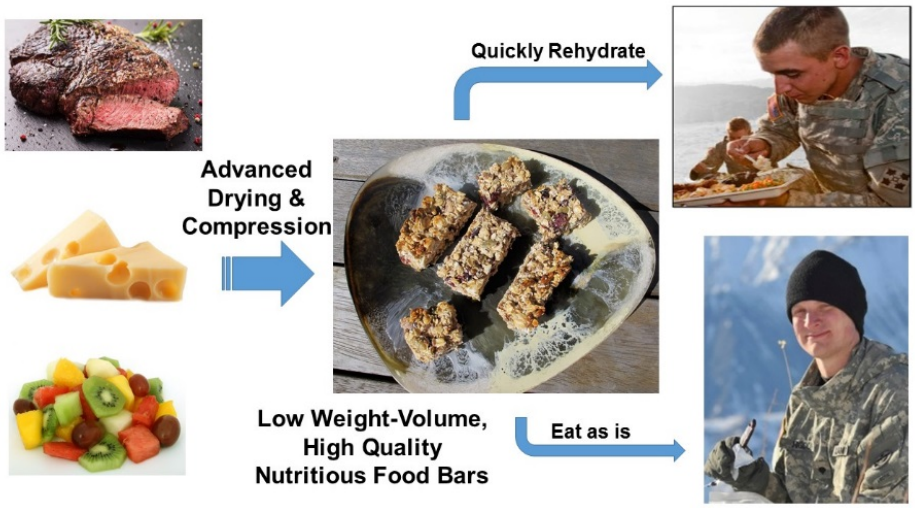

Figure 5. Application of the VMD technology

This document reports research undertaken at the U.S. Army Natick Soldier Research, Development and Engineering Center, Natick, MA, and has been assigned No. NATICK/TR- 20/008 in a series of reports approved for publication.

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APPENDIX A. Illustrations of starting material and drying in a rotational drum (E019) or tray (E040)

1. Starting material: Commercial fresh or frozen products (no further process or additive/preservative before drying)

2. Illustration of spinach leaves drying in a rotation drum (E019)

3. Illustration of macaroni and cheese drying in a carousel tray (E040)

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APPENDIX B. Illustrations of contract deliverables. Illustrations are VMD-compressed or VMD-vacuum packaged. Preparation procedures; type of drying (NutraREV or QuantaREV); drying parameters; initial weights and moisture contents; final weights, moisture contents and water activities; and percent weight and volume reductions.

a. Monterey Jack (Chewy)

NutraREV E040

Batch: ESBK051017E040NR-1
PREPARATION
Cube; 3% cellulose
Initial Moisture: 40%
NUTRAREV DRYING
Initial sample weight: 7950g
Vacuum: 25 ± 1 Torr
Critical Temperature: 95°C
Rotation: 40%

1. 8000 W @ 900 s
2. 4000 W @ 5600 s

Final sample weight: 2400g
Final moisture: 14.84%
Water activity: 0.8224
Temperature reached: 47°C (IR)
KWh used: 2.681 KWh
Drying rate: 0.895 kg/KWh
15% Sirach sauce in basket for Sirach flavor.
3-5% dry seasoning post-REV for seasoned cheese.
Weight Reduction: 70%
Volume Reduction: 70%

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b. Macaroni and Cheese

QuantaREV E040

Batch: BKSA271017E040QR-1
PREPARATION
Thaw and place into parchment lined trays.
Initial moisture: ~73%
QUANTAREV DRYING
Initial sample weight: 5290g
Vacuum: 25 ± 1 Torr
Critical Temperature: 80°C
Rotation: 60%

1. 5000 W @ 900 s
2. 4000 W @ 900 s
3. 3000 W @ 900 s

4. 2000 W @ 900 s

Final sample weight: 1855g
Water activity: 0.7165
Temperature reached: 61°C (top sensor)
KWh used: 3.402 KWh
Drying rate: 1.009 kg/KWh
Weight Reduction: 65%
Volume Reduction: 70%

---

c. Pizza Snacks
NutraREV E019

Batch: BK210817E019-1
PREPARATION
Place frozen into basket.
Initial moisture: 51%
NUTRAREV DRYING
Initial sample weight: 2015g
Vacuum: 25 ± 2 Torr
Rotation: 8 rpm

1) 2000 W @ 1200 s
2) 1000 W @ 1500 s

Final sample weight: 1230g
Final temperature: 62°C
Final moisture: 19.7%
Power used: 1.076 KWh
Rate of Drying: 0.730 kg/KWh
Weight Reduction: 39%
Volume Reduction: 20%

---

d. NY Cheesecake (Kirkland)
QuantaREV E040

Batch: BKSA211117E040QR-1
PREPARATION
Scrape off strawberry topping. Cut into 1" wide 2" long strips.
Initial moisture: 48%
QUANTAREV DRYING
Initial sample weight: 5525g
Vacuum: 25 ± 1 Torr
Critical Temperature: 80°C
Rotation: 60%

1. 4000 W @ 1800 s

Final sample weight: 3510g
Final moisture: 6%
Water activity: 0.4224
Temperature reached: 56°C (top sensor)
KWh used: 2.013 KWh
Drying rate: 1.000 kg/KWh
Weight Reduction: 37%
Volume Reduction: 20%

---

e. BBQ Beef

NutraREV E019

Batch: BBQ/Taco Beef, Gravy/Teriyaki Turkey

PREPARATION

Mix 1kg raw meat with 10% seasoning. Using plastic wrap roll into sausage shape. Boil until cooked. Slice to 0.75" thickness and freeze.
Initial moisture: 55%

NUTRAREV DRYING

Initial sample weight: 1010g
Vacuum: 25 ± 2 Torr
Rotation: 8 rpm

1) 1500 W @ 1100 s
2) 1000 W @ 400 s

Final sample weight: 560g
Water activity: 0.70
Power used: 0.574 KWh
Rate of Drying: 0.784 kg/KWh
Weight Reduction: 45%
Volume Reduction: 30%

---

f. Tyson Breakfast Sausage Patties

NutraREV E019

Batch:

PREPARATION

Put whole patties from frozen into basket
Initial moisture: 58%

NUTRAREV DRYING

Initial sample weight: 1885g
Vacuum: 25 ± 2 Torr
Rotation: 8 rpm

1) 2000 W @ 2100 s

Final sample weight: 945g
Water activity: 0.56

Power used: 1.157 KWh
Rate of Drying: 0.812 kg/KWh
Weight Reduction: 50%
Volume Reduction: 30%

---

g. Chicken Breakfast Sausage
NutraREV E019

Batch:
PREPARATION
Cut into 0.5" slices.
Initial moisture: 57%

NUTRAREV DRYING
Initial sample weight: 3585g
Vacuum: 25 ± 2 Torr
Rotation: 8 rpm

1) 2000 W @ 3995 s

Final sample weight: 1800g
Water activity: 0.73
Power used: 2.219 KWh
Rate of Drying: 0.80 kg/KWh
Weight Reduction: 50%
Volume Reduction: 40%

---

h. Ham
NutraREV E019

Batch:
PREPARATION
From Kirkland ham steaks. Cut into 0.5" cubes.
Initial moisture: 62%

NUTRAREV DRYING
Initial sample weight: 3280g
Vacuum: 25 ± 2 Torr
Rotation: 8 rpm

1) 2000 W @ 3660 s

Final sample weight: 1545g
Water activity: 0.78
Power used: 2.03 KWh
Rate of Drying: 0.807 kg/KWh
Weight Reduction: 53%
Volume Reduction: 40%

---

i. Hot Dog
NutraREV E019

Batch:
PREPARATION
Cut into 1" chunks.
Initial moisture: 57.9%
NUTRAREV DRYING
Initial sample weight: 4085g
Vacuum: 25 ± 2 Torr
Rotation: 8 rpm

1) 2000 W @ 4320 s

Final sample weight: 2055g
Water activity: 0.61
Power used: 2.381 KWh
Rate of Drying: 0.850 kg/KWh
Weight Reduction: 50%
Volume Reduction: 40%

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j. Italian Meatballs
NutraREV E019

Batch:
PREPARATION
Put whole into basket.
Initial moisture: 61%
NUTRAREV DRYING
Initial sample weight: 2760g
Vacuum: 25 ± 2 Torr
Rotation: 8 rpm

1) 2000 W @ 3200 s

Final sample weight: 1275g
Water activity: 0.72
Power used: 1.762 KWh
Rate of Drying: 0.843 kg/KWh
Weight Reduction: 54%
Volume Reduction: 40%

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k. Polish Sausage
NutraREV E019

Batch:
PREPARATION
Cut into 1" chunks. Kirkland Polish Sausage

Initial moisture: 47.7%
NUTRAREV DRYING
Initial sample weight: 3265g
Vacuum: 25 ± 2 Torr
Rotation: 8 rpm

1) 2000 W @ 2940 s

Final sample weight: 2145g
Water activity: 0.74
Power used: 1.633 KWh
Rate of Drying: 0.686 kg/KWh
Weight Reduction: 34%
Volume Reduction: 30%

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l. Summer Sausage
NutraREV E019

Batch:
PREPARATION
Put whole into basket.
Initial moisture: 36.5%
NUTRAREV DRYING
Initial sample weight: 1310g
Vacuum: 25 ± 2 Torr
Rotation: 8 rpm

1) 2000 W @ 1200 s

Final sample weight: 1020g
Water activity: 0.64
Power used: 0.667 KWh
Rate of Drying: 0.435 kg/KWh
Weight Reduction: 22%
Volume Reduction: 30%

---

m. Cheese Omelet
QuantaREV E040

Batch: BK260118E040NR-1
PREPARATION
Place onto trays.
Initial moisture: ~72%
QUANTAREV DRYING
Initial sample weight: 12730g
Vacuum: 25 ± 1 Torr
Critical Temperature: 80°C
Rotation: 60%

1. 10000 W @ 1440 s
2. 6000 W @ 1500 s
3. 4000 W @ 1800 s
4. 1500 W @ 600 s

Final sample weight: 4120g
Water activity: 0.7900
Final moisture: 14.80%
KWh used: 8.801 KWh
Drying rate: 0.978 kg/KWh
Weight Reduction: 68%
Volume Reduction: 30%

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n. Mini Quiche (Crustless)
QuantaREV E040

Batch: BK15011E040QR-1
PREPARATION
Place onto trays.
Initial moisture: ~63%
QUANTAREV DRYING
Initial sample weight: 4680g
Vacuum: 25 ± 1 Torr
Critical Temperature: 80°C
Rotation: 60%

1. 5000 W @ 1360 s
2. 2000 W @ 1420 s

Final sample weight: 2085g
Water activity: 0.6767
Final moisture: 10.25%
KWh used: 2.711 KWh
Drying rate: 0.957 kg/KWh
Weight Reduction: 56%
Volume Reduction: 30%

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o. French Toast
NutraREV E040

Batch: BK050218E040NR-1
PREPARATION

Initial Moisture: 44.9%
NUTRAREV DRYING
Initial sample weight: 3085g
Vacuum: 25 ± 1 Torr
Critical Temperature: 50°C
Rotation: 40%

1. 3000 W @ 762 s
2. 2000 W @ 1100 s

Final sample weight: 1825g
Final moisture: 7.06%
Water activity: 0.5548
KWh used: 1.597 KWh
Drying rate: 0.789 kg/KWh
Weight Reduction: 41%
Volume Reduction: 30% (will be higher if compressed)

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p. Tamago
NutraREV E040

Batch: BK050218E040NR-3
PREPARATION
Initial Moisture: 65%
NUTRAREV DRYING
Initial sample weight: 2010g
Vacuum: 25 ± 1 Torr
Critical Temperature: 50°C
Rotation: 40%

1. 2000 W @ 1044 s
2. 1500 W @ 695 s
3. 1000 W @ 900 s
4. 1500 W @ 1100 s

Final sample weight: 845g
Final moisture: 14.11%
Water activity: 0.7326
KWh used: 1.653 KWh
Drying rate: 0.705 kg/KWh
Weight Reduction: 58%
Volume Reduction: 40%

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q. Chewy Banana Chunks
QuantaREV E040

Batch: BKSA290917E040QR-1
PREPARATION

Cut into 1-2” chunks and place on trays.
Initial moisture: 76%

NUTRAREV DRYING
Initial sample weight: 14180 g
Vacuum: 29 ± 1 Torr
Critical Temperature: 50°C
Rotation: 55% 12-18 RPM

1. 10000 W @ 900 s
2. 8000 W @ 1200 s
3. 6000 W @ 1200 s
4. 4000 W @ 1200 s
5. 2000 W @ 900 s

Final sample weight: 3715g
Final moisture: 8.3%
Water activity: 0.5323
Temperature reached: 50.9°C (top sensor)
KWh used: 9.204 KWh
Drying rate: 1.14 kg/KWh
Weight Reduction: 74%
Volume Reduction: 70%

---

r. Blueberry (Chewy)
NutraREV E040

Batch: JZBK250118E40NR-6

PREPARATION
Air dry 80°C 4.5hr to 40-50% moisture.
Initial moisture: ~45%
QUANTAREV DRYING
Initial sample weight: 9000g
Vacuum: 25 ± 1 Torr
Critical Temperature: 50°C
Rotation: 55% (12 RPM)

1. 10000 W @ 1260 s

Final sample weight: 5400g
Final moisture: 8.3%
Water activity: 0.4837
Temperature reached: 47°C (IR)
KWh used: 3.543 KWh
Drying rate: 1.016 kg/KWh
Weight Reduction: 40%
Volume Reduction: 60%

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s. Chili Pepper
NutraREV E019

Batch: BKSA261017E019-3
PREPARATION
Place whole into basket.
Initial moisture: 72%
NUTRAREV DRYING
Initial sample weight: 500g
Vacuum: 25 ± 2 Torr
Rotation: 8 rpm

1) 2000 W @ 780 s
2) 700 W @ 240 s

Final sample weight: 155 g
Final temperature: 47°C
Final moisture: 14.48%
Water activity: 0.7248
Power used: 0.475 KWh
Rate of Drying: 0.726 kg/KWh
Weight Reduction: 69%
Volume Reduction: 80%

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t. Mixed Vegetable
QuantaREV E040

Batch: BKSA221117E040QR-1
PREPARATION
Air dry 2.5 h @ 75°C. Marinate overnight in 15% sauce.
Initial moisture: 65-66%
QUANTAREV DRYING
Initial sample weight: 7805g
Vacuum: 25 ± 1 Torr
Critical Temperature: 80°C
Rotation: 55%

1. 8000 W @ 600 s
2. 5000 W @ 1000 s
3. 2000 W @ 2400 s

Final sample weight: 3505g
Final moisture: 23.5% (average)
Water activity: 0.7001 (average)
KWh used: 4.173 KWh
Drying rate: 1.030 kg/KWh
Weight Reduction: 55%
Volume Reduction: 50%

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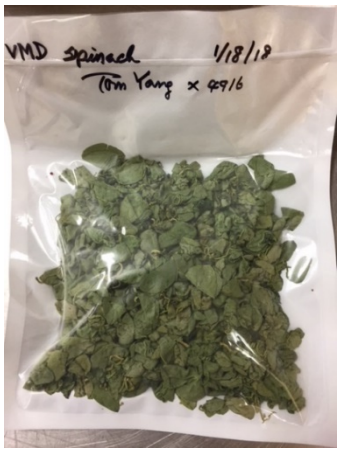
u. Spinach
NutraREV E019

Batch: BKSA271017E019-1
PREPARATION
Place whole into basket.
Initial moisture: 93.5%
NUTRAREV DRYING
Initial sample weight: 920g
Vacuum: 25 ± 2 Torr
Rotation: 8 rpm



1) 2000 W @ 1730 s
2) 700 W @ 240 s

Final sample weight: 85g
Final temperature: 30°C
Final moisture: 11.99%
Water activity: 0.6634
Power used: 0.948 KWh
Rate of Drying: 0.8808 kg/KWh
Weight Reduction: 91%
Volume Reduction: 90%

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APPENDIX C. Microbiological test of VMD products

Microbiological Analytical Laboratory Report								
Food Protection and Inovative Packaging Team								
	Microbiological Testing POC	Patrick Marek, Research Microbiologist						
	POC Contact	patrick.j.marek4.civ@mail.mil						
		508 233 6049						
	Product Name	Microwave assisted drying products						
	Requestor	T. Yang						
	Date received							
	Package Type	MRE foil w/vac						
	Sample incubation	10 days at 37						
	Lot number(s)							
	Item description	ID	PH	AW	Ecoli / Coliforms	APC	Yeast and Mold	Staph
1	Blackberry	BB1	3.2	0.7629	<10	50	100	<10
2		BB2	3.15	0.7616	<10	50	50	<10
3	Bacon cheddar cheese	BCC1	5.26	0.5783	<10	20	<10	<10
4		BCC2	5.34	0.5859	<10	50	<10	<10
5	M. Jack	MJ1	5.19	0.7665	<10	10	<10	<10
6		MJ2	5.18	0.7732	<10	<10	<10	<10
7	Pepper Jack	PJ1	5.24	0.6247	<10	<10	<10	<10
8		PJ2	5.25	0.6325	<10	15	<10	<10
9	Orange Mandarin	OM1	3.72	0.5157	<10	10	50	<10
10		OM2	3.77	0.5113	<10	10	100	<10
11	Jalapeno Jack	JJ1	5.09	0.6004	<10	200	10	<10
12		JJ2	5.18	0.601	<10	200	<10	<10
13	Siracha Pepper Jack	SPJ1	4.96	0.678	<10	200	175	<10
14		SPJ2	4.88	0.6119	<10	300	40	<10
15	Italian Herb Cheddar	IHC1	5.26	0.6187	<10	200	55	<10
16		IHC2	5.24	0.6187	<10	500	30	<10
17	Cheddar Cheese	CC1	5.32	0.6532	<10	10	<10	<10
18		CC2	5.27	0.6458	<10	10	<10	<10
	Special Instructions: Plate counts are provide in colony forming units (CFU's) per gram or milliter of sample; Limit of Detection is 10 CFU/g or ml ; TNTC= Too numerous to count; Results of these tests apply to above samples and the coresponding production							
	Comments: 1. Profucts are safe for consumption							

	Item description	ID	PH	AW	Ecoli / Coliforms	APC	Yeast and Mold	Staph
1	Strawberries, raw material	S1			<10	25	10	<10
2	Straberries, compressed	S2			<10	55	<10	<10
3	Cheesecake	C1			<10	10	<10	<10
4	Banana, raw material	BR			10	0	>1000	<10
5	Banana, compressed	BC			10	15	>1000	<10
6	Bacon Cheddar	2C			<10	30	<10	<10
7	Bacon Cheddar, compressed	3C			<10	40	<10	<10
8	Jalapeno Jack Cheese	J			<10	165	15	<10
9	Jalapeno Jack Cheese, compressed	JC			<10	185	70	<10
	Special Instructions: Plate counts are provide in colony forming units (CFU's) per gram or milliter of sample; Limit of Detection is 10 CFU/g or ml ; TNTC= Too numerous to count; Results of these tests apply to above samples and the coresponding production							

Comments: 1. Products tested are safe for consumption.
2. The higher yeast and mold counts for the banana products are expected.

	Item description	ID	PH	AW	Ecoli / Coliforms	APC	Yeast and Mold	Staph
1	VMD Dark Chocolate Cheese cake	D1	5.55	0.6576	15	45	<10	<10
2		D2	5.75	0.6551	10	60	<10	<10
3		D3	5.73	0.6494	<10	25	<10	<10
4	VMD Blueberry Cheese cake	B1	5	0.6324	<10	55	<10	<10
5		B2	4.97	0.6407	<10	60	<10	<10
6		B3	5.07	0.645	<10	50	<10	<10
7	VMD Cranberry Cheese cake	C1	4.81	0.6069	<10	60	<10	<10
8		C2	5.28	0.6375	<10	80	<10	<10
9		C3	4.82	0.6179	<10	105	<10	<10
	Special Instructions: Plate counts are provide in colony forming units (CFU's) per gram or milliter of sample; Limit of Detection is 10 CFU/g or ml ; TNTC= Too numerous to count; Results of these tests apply to above samples and the coresponding production							

Comments: 1. Products are safe for consumption

	Item description	ID	PH	AW	Ecoli / Coliforms	APC	Yeast and Mold	Staph
5	Ham Quiche	HQ1	6.00	0.7278	<10	25	<10	<10
6		HQ2	6.05	0.7187	<10	10	<10	<10
7	Cheese Omelet	CO1	6.91	0.7458	<10	35	<10	<10
8		CO2	6.7	0.7429	<10	10	<10	10
9	Cheese Quiche	CQ1	5.86	0.7759	<10	35	<10	<10
10		CQ2	5.82	0.7873	<10	50	<10	<10
11	Spinach Quiche	SQ1	5.95	0.7876	<10	190	<10	<10
12		SQ2	5.98	0.8069	<10	20	<10	<10
13	Tomago	T1	7.03	0.7232	<10	10	10	<10
14		T2	7.06	0.7263	<10	<10	10	<10
15	Veggie Omelet	VO1	6.91	0.5342	<10	20	<10	<10
16		VO2	6.87	0.5385	<10	10	<10	<10
19	French Toast	FT1	6.31	0.5498	<10	35	<10	<10
20		FT2	6.22	0.5315	<10	<10	10	<10
21	Bacon Quiche	BQ1	6.1	0.8087	<10	20	<10	<10
22		BQ2	6.13	0.8139	<10	875	<10	<10

	Item description	ID	PH	AW	Ecoli / Coliforms	APC	Yeast and Mold	Staph
1	Siracha Jack Cheese	SJC1	5.19	0.7914	<10	385	<10	<10
2		SJC2	5.19	0.7908	<10	450	<10	<10
7	Chicken breakfast sausage	CBS1	6.45	0.7659	<10	285	<10	<10
8		CBS2	6.44	0.7665	<10	500	<10	<10
11	1000 Island Root Veg and Ham	RVH1	5.39	0.783	<10	285	65	<10
12		RVH2	5.23	0.7855	<10	90	15	<10
13	Italian Meatball	IM1	6.13	0.7663	<10	105	<10	<10
14		IM2	6.11	0.7525	<10	65	<10	<10
15	Polish Sausage	PS1	5.76	0.7667	<10	<10	<10	<10
16		PS2	5.76	0.7711	<10	<10	<10	<10
17	Breakfast Sausage Patty	BSP1	6.3	0.6753	<10	<10	<10	<10
18		BSP2	6.3	0.6723	<10	<10	<10	<10
19	Chicken Pineapple Sausage	CPS1	6.39	0.7442	<10	<10	<10	<10
20								