Investigation into Gluten Metabolizing Bacterial Species and their Inhibition

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Abstract
Environmental sources and domestic pets’ oral microbiomes were sampled for the presence of gluten metabolizing bacteria. Isolated bacteria were grown on gluten agar and challenged with Over The Counter (OTC) oral hygiene products and bacterial antagonistic bacteriocins to discover strains of gluten metabolizing bacteria that could potentially be utilized as a probiotic. Sixteen strains were isolated that were gluten metabolizers but only one strain was significantly more resistant to OTC oral hygiene products and to antagonistic bacterial bacteriocins. This newly isolated commensal strain may prove to be a potent gluten metabolizing probiotic. The oral microbiomes of household pets were not a significant source of gluten metabolizers.

Keywords: Gluten, Microbiome, Oral anti-microbial products.
Abbreviations: CD-Celiac Diseases, OTC-Over The Counter, TSA-Trypticase Soy Agar.

Introduction
It has been previously reported that the gluten metabolizing bacteria in the oral biofilm are involved in the digestion and processing of gluten containing food products, such as, Rothia aeria and R. mucilaginosa. While the human digestive enzyme system lacks the capacity to cleave the immunogenic gluten, such activities are naturally present in the oral microbial enzyme repertoire. Therefore, the human microbiome contributes significantly to the digestion of food, especially the oral microbiome [1,2]. The oral microbiome is very rich in microbial species, with over 1000 taxa so far identified. The estimated numbers of bacteria in dental plaque and saliva are 10¹⁴ per gram of dental plaque and 10⁷ per ml of saliva, making the oral cavity the second most densely colonized part of the human digestive tract after the colon. In addition, saliva contains a wide variety of species that differ distinctly from the communities in the gut [3-8].

It has been published that the oral microbiome is a novel and rich source of gluten degrading enzymes originating from the oral microbiome. This is quite important because mammalian digestive enzymes are reportedly only partly capable of cleaving gluten, and fragments remaining induce toxic responses in celiac predisposed individuals. The effect of the microbiome on individuals, with and without Celiac Diseases (CD) was reported by Cameron demonstrating the role of gluten metabolizing bacteria [9-11].

In that study the role of the genus Lactobacillus was strongly implicated. In another recently reported study, four strains from the species Lactobacillus ruminis, Lactobacillus johnsonii, Lactobacillus amylovorum and Lactobacillus salivarius, isolated from the proximal gastro-intestinal tract showed the highest peptide-degrading activities.

These strains displayed different degradation rates and cleavage patterns that resulted in the reduction but not the complete removal of immunogenic epitopes. This underscores the importance of the human microbiome in digestion of food [12].

In addition, it is estimated that over one liter of saliva is swallowed every day, taking the oral microbiome into the proximal gastrointestinal tract, affecting digestion and the gastro-intestinal microbial constituency. A new area of study, the effects of bacteria on the metabolic end-products, and the effects of the metabolome on genetic expression, referred to as epigenetics, further emphasizes the importance of studying the oral microbiome. Probiotic bacteria to remedy gluten sensitivity have been recommended and clinical trials are progressing. What is interesting is that many of these suggested probiotics for CD are already probiotics commercially available [13-15].

Previous studies implied the importance of these bacteria for societies consuming the modern “western” diet. Also present in the modern “western” society is a reported increase in Irritable Bowel Disease due to an alteration in the gut microbiome. In addition, western culture also emphasizes the use of oral medications, ostensibly to promote oral health. Over The Counter products may alter the oral microbiome creating a situation less conducive for the survival of essential beneficial bacteria [16-19].

Indeed, the uses of OTC oral mouth rinses have been linked to high blood pressure, erectile dysfunction, low capillary re-perfusion, diabetes, and obesity. It is postulated that the use of OTC products may...
decrease the enzymatic degradation of gluten containing foods by *Rothia* bacteria resulting in gluten sensitivity. Irritable Bowel Syndrome (by the resultant shift in the gut microbiome), and exacerbating ulcerative colitis increasing Celiac disease clinical prevalence. In a previous research study, some of these oral medicaments were determined to greatly inhibit the gluten metabolizers in *vitro*. Therefore, the importance of the gluten metabolizing bacteria should not be minimized and deserves further investigation into why some people have a decreased level of these essential probiotics. The literature also does not report how commonly the gluten metabolizing bacteria are present in our environment and in the oral cavity of other mammals [20-23].

**Objective**

To isolate previously undiscovered gluten metabolizing bacterial species from environmental sources and to determine the factors, such as Over the Counter mouth rinses and antagonistic bacteria responsible for their inhibition.

**Materials and Methods**

Previously non-investigated sources of bacteria capable of digesting gluten were determined and the sites cultured with swabbing using the Amies collection media. The sites were commonly found areas where grain was reduced to flour, such as, grain mills, and bakeries using non-bleached flour. The animal sources included common household pets. The collected samples were incubated on gluten agar and the colonies isolated. Colonies of bacteria growing on gluten agar were sub-cultured to fresh gluten agar to confirm gluten utilization. Putative gluten utilizing bacterial were then identified to genus and species level by standard laboratory methods [24].

**Susceptibility Experiment**

The inhibitory effects of various oral mouth wash and other oral preparations were tested using a Kirby-Bauer type assay. Oral bacteria of interest were grown in Mueller-Hinton media to a McFarland Standard of 0.5. Trypticase Soy agar plates with 5% sheep blood were wholly spread with one cotton swab inoculation of chosen bacteria to create a bacterial lawn. Blank cotton discs were evenly distributed on the plate and 10 or 20 microliters of full strength test substrate was pipetted directly onto each corresponding disc. Gluten metabolizing bacteria were challenged with previously investigated known oral medicaments that inhibit the *Rothia* genus. The plates were evaluated after 30 hours of growth at 36°C. Calipers were used to measure zones of inhibition in millimeters.

**Bacteriocin Detection Studies**

Trypticase Soy Agar (TSA) was autoclaved and cooled to 56 degrees and aliquots of 25mL were cooled and inoculated with 2mL of 0.5 McFarland Standard suspensions of the experimental bacteria prior to pouring agar plates. Impregnated plates were then inoculated in punched zones using a disposable 10 microliter pipet with 0.5 McFarland Standards of bacteria species: *Streptococcus salivarius*, *Staphylococcus aureus*, *Vancomycin-resistant Enterococcus*, *Pseudomonas aeruginosa*, *Escherichia coli*, and *R. dentocariosa* or *R. mucilaginosus*. The plates were evaluated after 24 hours of growth at 36°C. Calipers were used to measure zones of inhibition. Bacteriocin assays were also performed on the *Rothia* species, and the newly isolated gluten metabolizers, MLC 124, LJ 514, AM 419 and BK as target strains.

**Results**

Oral medicaments such as CrestTM, ListerineTM, Act™ Fluoride rinse, Chlorhexidine, and Smart Rinse™ inhibited all 16 of the new gluten metabolizing bacterial strains (average 10 mms.). One strain MLC 124 was more resistant to oral medications. Xyitol products only inhibited 9 strains, but not MLC 124. Forty isolates were screened for bacteriocin activity with *Rothia* species and the newly isolated bacteria as targets. No zones of inhibition were detected with strain identified as MLC 124. The 15 Factor a Groups demonstrated significant differences as to Sensitivity to Oral Medicaments (DF 14, P=0.0005). The following groups presented with significant differences (Bonferroni pair testing): A1 vs B2, B1 vs B2, A1 vs B3, B1 vs B3, B2 vs B5, B3 vs B6, B2 vs B5, and B2 vs B6.

**Discussion**

Nonpathogenic environmental and non-human gluten metabolizing bacteria may prove beneficial as a source of probiotic strains. Further identification of potentially beneficial bacteria is recommended and may be of great importance. This study examined additional microbial strains that were determined to already be present in the human oral microflora, but were never previously considered to have any identifiable purpose. Additionally, use of anti-microbial products appears to have a more global influence than may have been believed. Although great caution should be used when interpreting in vitro laboratory data into clinically relevant results, pilot studies into the effects of oral medicaments should increase further research efforts investigating these potential issues.

| Isolate | Putative ID | SPRY 10 | SPRY 20 | Crest 10 | Crest 20 | CHX 10 | CHX 20 | ACT 10 | ACT 20 | Listene 10 | Listene 20 | Smart 10 | Smart 20 |
|---------|-------------|--------|--------|---------|---------|--------|--------|--------|--------|-----------|-----------|----------|----------|
| A1      | Yeast       | 0      | 8      | 0       | 6       | 0      | 8      | 0      | 10     | 0         | 0         | 0        | 0        |
| A2      | resembles *Rothia aquatilis* | 8      | 12     | 6       | 12      | 12     | 10/14  | 10     | 10     | 0         | 6         | 0        | 6        |
| A3      | resembles *Rothia aquatilis* | 10     | 10     | 6       | 10      | 6      | 10     | 8      | 0      | 0         | 0         | 0        | 0        |
| A4      | *E. vulneris* | 8      | 10     | 8      | 10/6    | 14     | 10     | 12     | 0      | 6         | 6         | 6        | 6        |
| A5      | resembles *Rothia aquatilis* | 0      | 10     | 6       | 10      | 10     | 14/16  | 8      | 12     | 0         | 6         | 0        | 6        |
| A6      | Enterobacter sp. | 6      | 8      | 6       | 8       | 8      | 12     | 8      | 10     | 0         | 6         | 0        | 0        |
| A7      | Enterobacter sp. | 0      | 10     | 10      | 14      | 14     | 10/14  | 8/14   | 6      | 8         | 10        | 10       | 10       |
| A8      | Enterobacter sp. | 6      | 8      | 6       | 8       | 8      | 10     | 8      | 0      | 0         | 0         | 0        | 0        |
| A9      | *Bacillus sp. (not cereus)* | 6      | 8      | 6       | 10      | 6      | 12     | 6      | 10     | 0         | 0         | 0        | 0        |
| B1      | *Bacillus sp. (not cereus)* | 6      | 8      | 6       | 10      | 10     | 12     | 8      | 10     | 0         | 0         | 0        | 8        |
| B2      | Enterobacter sp. | 0      | 0      | 6       | 10      | 8      | 10     | 6      | 8      | 0         | 6         | 6        | 8        |
| B3      | *Bacillus pumilus* | 0      | 0      | 8       | 10      | 10     | 12     | 8      | 10     | 0         | 8         | 10       | 10       |
| B4      | Gram Neg Cococobacilli | 0      | 0      | 0       | 8       | 8      | 8      | 8      | 0      | 0         | 0         | 0        | 0        |
| B5      | *E. vulneris* | 0      | 0      | 0       | 8       | 8      | 10     | 8      | 0      | 0         | 0         | 0        | 0        |
| B6      | *E. vulneris* | 0      | 0      | 0       | 8       | 8      | 10     | 8      | 0      | 0         | 0         | 0        | 0        |
| B7      | *S. marcescens* | 0      | 0      | 6       | 8       | 6      | 10     | 6      | 0      | 0         | 0         | 0        | 0        |

**Table 1:** Mammalian gluten metabolizers and inhibition by oral medicaments. Zones of inhibition are listed in millimeters.

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A statistically significant result was demonstrated within and between the 15 bacterial strains as to sensitivity to oral medicaments. This should indicate that certain bacterial strains are more resistant to oral medicaments and would possibly be beneficial as gluten metabolizing probiotic strains without concern as to oral hygiene products being used by our patients.

Further research into the role of gluten metabolizing oral strains is warranted, as is the development of gluten metabolizing probiotics. Oral health professionals should be concerned over the overuse of antimicrobials in hygiene products, not just because of the effects on oral health professionals should be concerned over the overuse of antimicrobials in hygiene products, not just because of the effects on oral health, but also because of the possible gastro-intestinal strain shifting. This may, possibly even create epigenetic events in the host. As a result, antimicrobial oral hygiene products

### Table 2: Isolates from non-human sources inhibition by oral medicaments.

| Mammal Isolate | SPRY | Crest | CHX | ACT | Listerine | Smart |
|----------------|------|-------|-----|-----|-----------|-------|
| A1             | 0    | 0     | 0   | 0   | 0         | 0     |
| A2             | 0    | 0     | 0   | 0   | 0         | 0     |
| A3             | 0    | 0     | 0   | 0   | 14        | 16    |
| A4             | 0    | 0     | 0   | 0   | 16        | 24    |
| A5             | 0    | 0     | 0   | 0   | 14        | 18    |
| A6             | 0    | 0     | 0   | 0   | 14        | 0     |
| A7             | 0    | 0     | 0   | 0   | 20        | 18    |
| A8             | 0    | 0     | 0   | 0   | 14        | 14    |
| A9             | 0    | 0     | 0   | 0   | 0         | 30    |
| B1             | 0    | 0     | 0   | 0   | 0         | 0     |
| B2             | 0    | 0     | 0   | 0   | 24        | 24    |
| B3             | 0    | 0     | 0   | 0   | 24        | 26    |
| B5             | 0    | 0     | 0   | 0   | 0         | 0     |
| B6             | 0    | 0     | 0   | 0   | 6         | 0     |

### Table 3: Bacitracin screen.

| Isolate | SPRY | Crest | CHX | ACT | Listerine | Smart |
|---------|------|-------|-----|-----|-----------|-------|
| NG2     | Y/4  | Y/0   | Y/10| N/0 | N/0       | Y/4ot |
| NG4     | Y/4  | Y/0   | Y/14| N/0 | N/0       | Y/2   |
| HN1     | Y/0  | Y/0   | Y/0 | Y/0 | Y/0       | Y/0   |
| HN2     | Y/0  | Y/0   | Y/0 | Y/0 | Y/0       | Y/0   |
| LL1     | Y/6  | Y/0   | Y/12| N/0 | N/0       | Y/0   |
| LL2     | Y/5  | Y/0   | Y/8 | N/0 | Y/0       | Y/6   |
| LL3     | Y/5  | Y/0   | Y/6 | N/0 | Y/0       | Y/0   |
| L1      | Y/0  | Y/0   | Y/5 | Y/0 | Y/0       | Y/4   |
| K1      | Y/6  | Y/0   | Y/14| N/0 | Y/0       | Y/0   |
| K1T     | Y/0  | Y/0   | Y/12| N/0 | N/0       | Y/4   |
| FD1     | Y/0  | Y/0   | Y/10| Y/0 | Y/0       | Y/0   |
| FD2     | Y/0  | Y/0   | Y/6 | Y/0 | Y/0       | Y/0   |
| DLZ     | Y/0  | Y/0   | Y/10| Y/0 | Y/0       | Y/6   |
| Dol    | Y/12 | Y/0   | Y/10| Y/0 | Y/0       | Y/0   |
| GTP     | Y/0  | Y/0   | Y/18| Y/0 | Y/0       | Y/0   |
| Euvora a | N/0  | N/0   | Y/0 | N/0 | Y/0       | Y/3   |
| Euvora s | N/0  | N/0   | Y/0 | Y/0 | Y/0       | Y/0   |
| 45pre   | Y/4  | Y/0   | Y/18| N/0 | Y/0       | Y/3   |
| 49pre   | Y/0  | Y/0   | Y/12| N/0 | Y/0       | Y/2   |
| Nucle   | Y/0  | Y/0   | Y/0 | Y/0 | Y/0       | Y/5   |
| 31P     | N/0  | Y/0   | Y/4 | N/0 | N/0       | Y/0   |
| Rock1a  | Y/0  | Y/0   | Y/0 | Y/0 | N/0       | Y/0   |
| Rock2a  | Y/0  | Y/0   | Y/18| Y/0 | Y/0       | Y/0   |
| Rock3a  | Y/0  | Y/0   | Y/10| Y/0 | Y/0       | Y/0   |
| B1R     | Y/5  | Y/0   | Y/6 | N/0 | Y/0       | Y/0   |
| B2R     | Y/0  | Y/0   | NA  | Y/0 | Y/0       | Y/4   |
| B3R     | Y/0  | Y/0   | NA  | Y/0 | Y/0       | Y/0   |
| B4R     | Y/0  | Y/0   | Y/5 | Y/0 | Y/0       | Y/0   |
| DL1     | Y/0  | Y/0   | Y/10| Y/0 | N/0       | Y/5   |
| HNs     | Y/0  | Y/0   | Y/0 | Y/0 | Y/0       | Y/0   |
| HN6     | Y/0  | Y/0   | NA  | N/0 | N/0       | Y/0   |
| HN7     | Y/0  | Y/0   | Y/0 | Y/0 | Y/0       | Y/0   |
| FD3     | Y/0  | Y/0   | Y/12| N/0 | N/0       | Y/0   |
| Fin     | Y/0  | Y/0   | Y/10| Y/0 | Y/0       | Y/3   |
| FD5     | Y/0  | Y/0   | Y/8 | Y/0 | Y/0       | Y/0   |
| DL2     | Y/0  | Y/0   | Y/8 | Y/0 | Y/0       | Y/0   |
| L2      | Y/0  | Y/0   | Y/8 | Y/0 | N/0       | Y/0   |
| AS1     | Y/0  | Y/0   | Y/0 | Y/0 | N/0       | Y/0   |
| AS2     | Y/0  | Y/0   | Y/0 | Y/0 | N/0       | Y/0   |
| KT1     | Y/0  | Y/0   | N/6 | Y/0 | N/0       | Y/6   |
| A1      | Y/0  | Y/0   | Y/0 | Y/0 | Y/0       | Y/0   |
| A2      | N/0  | Y/0   | N/0 | N/0 | N/0       | N/0   |
| A3      | N/0  | Y/0   | N/0 | N/0 | N/0       | N/0   |
| A4      | Y/0  | Y/0   | Y/0 | Y/0 | Y/0       | Y/0   |
| A5      | Y/0  | Y/0   | Y/0 | N/0 | N/0       | Y/0   |
| A6      | Y/0  | Y/0   | Y/0 | N/6 | Y/0       | Y/0   |
| A7      | Y/0  | Y/0   | Y/0 | Y/0 | Y/0       | Y/0   |
| A8      | Y/0  | Y/0   | N/0 | N/0 | N/0       | Y/0   |
| A9      | N/0  | Y/0   | N/0 | N/0 | N/0       | Y/0   |
| B1      | N/0  | Y/0   | N/0 | N/0 | N/0       | Y/0   |
| B2      | N/0  | N/0   | N/0 | N/0 | N/0       | Y/0   |
| B3      | N/0  | Y/0   | N/0 | N/0 | N/0       | Y/0   |

### Figure 1: Statistical analysis with Degree of Freedom (DF), Sum of Squares (SS), Mean of Squares (MS) and F (ratio between and within groups). The P value is the probability of achieving value. The results were statistically significant.

### Figure 2: Example of plates demonstrating inhibition zones. Values were measured in millimeters with a laboratory caliper.
should only be utilized under the direct supervision of a dental specialist. In theory, all medications should be screened on an individual basis not only for appropriateness and efficacy, but possible untoward sequelae.

Discovery of additional gluten metabolizing bacterial species should be continued with emphasis on finding strains that are resistant to antibiotics, microbial antagonists and over the counter products. Ideally, these gluten metabolizers would also be beneficial probiotics, inhibiting pathogens and positively modulating the host immune response. Specifically because humans have not evolved to properly manage the significant changes to our diet and environment, especially since the start of the Neolithic agricultural revolution. But apparently, our microbiome has evolved to help accommodate our dietary “adventures”. Unfortunately, the more recent “fast food” revolution, along with the great expansion of preserved convenience food, has further challenged the human oral and gut microbiome by reducing in quantity, many commensal and probiotic bacterial strains previously found in the diet. An additional complication is the hygienic conditions now used to prepare food. Grain that was ground into flour by an exposed stone wheel had a rich abundance of naturally present gluten metabolizers. Not so in present times as the flour facilities are kept so clean, the flour is most often bleached, killing off an essential source of the gluten probiotics. Possibly all commercial flour should be fortified with gluten metabolizers that are potent probiotics. Further research should be performed to test the limits of this proposed solution.

Household pets were not a significant source of gluten metabolizers, and some strains were inhibited by OTC oral products. Household pets are often referred to as “facultative” or “obligatory” carnivores, and as such, should not have gluten metabolizers as significant contributors to their oral microbiome. Obviously, they should not be fed high gluten pet foods.

Conclusion

Newly discovered bacterial strains capable of digesting gluten that are resistant to oral antimicrobial agents and antagonistic (bacteriocin producing) bacteria were isolated from flour “environments”.

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