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ABSTRACT

To investigate the effects of raffinose and encapsulated *Bifidobacterium breve* JCM 1192<sup>T</sup> cells administration on rat cecal microbiota, as a preclinical synbiotic study, groups of male WKAH/Hkm Scl rats were fed for three weeks with four different test diets: basal diet (BD), BD supplemented with raffinose (RAF), BD supplemented with encapsulated *B. breve* (CB), and BD supplemented with both raffinose and encapsulated *B. breve* (RCB). The bacterial populations of cecal samples were determined by fluorescence *in situ* hybridization (FISH) and terminal restriction fragment length polymorphism (T-RFLP). *B. breve* cells were detected only in the RCB diet group and represented about 6.3% of the total cells as determined by FISH analysis. The presence of *B. breve* was also detected only in the RCB group by T-RFLP analysis. This was in contrast to the CB group in which no *B. breve* signals were detected by either FISH or T-RFLP. Increase of the population of *Bifidobacterium animalis*, an indigenous *Bifidobacterium* of the rat, was observed in the RAF and RCB groups. Principal component analysis of T-RFLP results revealed significant alterations in the bacterial populations of rats in the RAF and RCB groups; the population in the CB group was similar to that of the control (BD) group. To the best of our knowledge, these results provide the first clear picture of the changes of rat cecal microbiota in response to the synbiotic administration.
The human gastrointestinal tract harbors various kinds of bacteria that may affect positively or negatively on the health conditions of the host (9). There is an increasing interest in the idea that diet can promote or maintain beneficial colonic bacteria that improve immunopotentation (25), prevent the invasion of pathogenic bacteria (45), and provide metabolic energy for the host (17). This concept has led to the terms ‘probiotic’ (15), ‘prebiotic,’ (17) and ‘synbiotic’ (17).

Synbiotic was first defined as a mixture of probiotics and prebiotics that beneficially affects the host by improving the survival and implantation of live microbial dietary supplements in the gastrointestinal tract by selectively stimulating the growth and/or by activating the metabolism of one or a limited number of health promoting bacteria and thus improving host welfare (17). Synbiotics are believed to increase the persistence of the probiotic bacteria in the gastrointestinal tract. Although concept of synbiotics has been introduced, clear demonstration of synbiotic effects seems not available in the literature due to unclear experimental design or unreliable methods for microbiota analysis. Molecular ecological methods, which reveal the entire range of bacterial diversity and more accurately detect population changes, are now considered more appropriate for evaluating synbiotic effects.

In this study, alteration of rat cecal microbiota upon administration of raffinose in combination with Bifidobacterium breve JCM 1192T was analyzed. B. breve JCM 1192T was employed in gelatin-encapsulated form to protect the bacterial cells from the acidic environment of the stomach and to increase bacterial access to the intestine. This strain has recently been reported to accumulate large amounts of cholic acid, a primary bile acid in humans, in an energy-dependent manner (26). Thus, we intended to amplify this strain in rat cecum as a preclinical study to design rational human trial to see the effects on lipid metabolism and on intestinal bile acids composition. In in vitro growth experiments, B. breve
JCM 1192ᵀ grew better on raffinose than on the other fermentable sugars tested. Therefore, raffinose was chosen as suitable carbon source in combination with encapsulated *B. breve* JCM 1192ᵀ. Although this mixture, i.e. raffinose and encapsulated *B. breve* JCM 1192ᵀ, has not yet been demonstrated as a synbiotic in accord with Gibson and Roberfroid’s definition (17), we sometimes call this mixture “synbiotic” for simplicity and clarity in the text. Similarly, encapsulated *B. breve* JCM 1192ᵀ is tentatively referred to as “probiotic”. Rat experiment was designed in four groups (control, prebiotic, probiotic and synbiotic). Two molecular techniques, fluorescence *in situ* hybridization (FISH) (4) and terminal restriction fragment length polymorphism (T-RFLP) analyses (31, 29) were applied for the first time to monitor rat microbiota alteration in synbiotic experiment. As the result, proliferation of *B. breve* JCM 1192ᵀ was successfully observed only in synbiotic group. Furthermore, we have analyzed other members of rat microbiota and determined organic acids content in cecum to obtain more comprehensive picture of the changes of rat intestinal microbiota. We believe these results can provide the first clear picture of microbiota changes in rat cecum upon administration of synbiotic, and can add fundamental knowledge to rat intestinal microbiology.

**MATERIALS AND METHODS**

**Bacterial strain and media.** *B. breve* JCM 1192ᵀ was obtained from the Japan Collection of Microorganisms (JCM, Wako, Japan). Cultures were conducted in MRS medium (11) prepared at half strength (1/2 MRS) containing filter-sterilized L-cysteine.HCl at a concentration of 0.25 g/l unless otherwise stated. TOS Propionate Agar (Yakult Pharmaceutical Ind. Co., Ltd., Tokyo, Japan) was used for the isolation of bifidobacteria from rat cecal samples.
Measurement of the growth rate. Seed culture for the growth experiments of *B. breve* JCM 1192\(^T\) was conducted overnight in 1/2 MRS. The seed culture was transferred to the same medium at the optical density at 660 nm \(\text{OD}_{660}\) of 0.05, but containing one of the following five carbohydrates (10 g/l): glucose, sucrose, raffinose (Sigma-Aldrich, St. Louis, Mo.), kestose and nystose (both donated from the Hokuren Federation of Agricultural Cooperatives, Sapporo, Japan). Bacterial growth was periodically monitored by measuring \(\text{OD}_{660}\) of the culture broth. All the cultures were carried out at 37 °C under anaerobic conditions using mixed gas \((\text{N}_2/\text{CO}_2/\text{H}_2; 8:1:1)\). Specific growth rates \((\mu, \text{h}^{-1})\) were calculated during logarithmic growth phase using the equation: 

\[
\mu = \frac{\ln x_{t2} - \ln x_{t1}}{(t2-t1)},
\]

where \(x_{t2}\) and \(x_{t1}\) are \(\text{OD}_{660}\) at time \(t2\) and time \(t1\), respectively.

Animals and diets. Male WKAH/Hkm Slc rats \((n = 24, \text{Japan SLC, Hamamatsu, Japan})\), aged 4 weeks old, were acclimatized with basal diet for 7 days in individual rat cages. Twenty four rats were divided equally into 4 groups and fed test diets for three weeks. The control group (BD) received basal diet, which contained (g/kg diet): casein, 250; corn oil, 50; AIN-93G mineral mixture, 35; AIN-93 vitamin mixture, 10; choline bitartrate, 2.5; and sucrose, 602.5; supplemented with crystalline cellulose (Avicel, Asahi Kasei Corporation, Osaka, Japan), 50 g/kg diet (35). Diet group 2 (RAF) received BD supplemented with raffinose (Nippon Beet Sugar Manufacturing Co., Ltd., Tokyo, Japan), 30 g/kg diet. Diet group 3 (CB) was fed BD supplemented with gelatin-encapsulated *B. breve* JCM 1192\(^T\) (provided by Morishita Jintan Co., Ltd., Osaka, Japan) with a viable cell count of about 5.7 x 10\(^7\) CFU/g capsule), 30 g/kg diet. The gelatin content of the capsule was 17.5% (w/w). Thus, CB group received 5.25 g gelatin/kg diet. For the preparation of the capsule, *B. breve* JCM 1192\(^T\) was cultured in a jar fermentor until late exponential growth phase using 1/2 MRS medium containing both 40 g/l raffinose as the carbon source and 0.5 g/l L-cysteine.HCl. The culture was conducted at 37 °C by stirring at 200 rpm under anaerobic conditions with CO\(_2\).
gas into the headspace of the fermentor. The pH of the medium was controlled at 6.5 with NaOH. The cells were harvested by centrifugation, washed twice with 150 mM NaCl, resuspended in 10% (w/v) skim milk, and then freeze-dried before encapsulation. Diet group 4 (RCB) received BD supplemented with raffinose and encapsulated *B. breve* JCM 1192<sup>T</sup> in the same amounts as in the RAF and CB diets, respectively. Rats were maintained and handled according to the recommendations of our Institutional Ethics Committee.

**Sample preparation.** Individual rat cecal contents were immediately weighed after sacrificing rats. One portion of the contents was used for pH and organic acid measurements (see measurement of organic acids). The remainder (about 0.5 g) was washed three times with ice-cold phosphate-buffered saline (PBS; 130 mM NaCl, 10 mM sodium phosphate buffer, pH 7.2) with low-speed centrifugation at 200 x g for 5 min. Bacteria were pelleted from the pooled supernatant by high-speed centrifugation three times at 9000 x g for 2 min each time. The bacterial cell pellet was resuspended in PBS and divided into two parts. The first part was used for bacterial cell fixation for FISH analysis (see FISH analysis). As sample amounts were limited, the remaining parts were pooled according to test diet group for genomic DNA extraction for T-RFLP analysis (see T-RFLP analysis).

**Measurement of organic acids.** The concentrations of organic acids (succinate, lactate, propionate, butyrate, isovalerate, and valerate) in the rat cecal samples were measured by HPLC (SCL-10AVP, Shimadzu Corporation, Tokyo, Japan) according to the method described previously (18). Briefly, the cecal samples were added to sodium hydroxide aqueous solution containing crotonic acid as an internal standard. After centrifugation, the fat-soluble substances in the supernatant were removed by extraction with chloroform. The aqueous phase was passed through a membrane filter and subjected to HPLC.

**FISH analysis.** Individual washed samples were fixed in 4% (w/v) paraformaldehyde in PBS (pH 7.2) for 24 h. Fixed samples were washed once in PBS and stored
in a known volume of 50% (v/v) ethanol/PBS at –20°C until use. Aliquots of 3 µl of fixed
cells were applied to Teflon printed glass slides (ADCELL, 12 wells, 5 mm in diameter, Erie
Scientific Company, Portsmouth, N.H.) and air-dried. The cells were then dehydrated
through a series of 50%, 80%, and 99.5% ethanol for 3 min each. The cells fixed on the glass
slides were hybridized by addition of 8 µl of hybridization buffer (0.9 M NaCl, 0.01% SDS,
20 mM Tris-HCl, 20% deionized formamide, pH 7.2) with 1 µl of Cy3-labeled
oligonucleotide probe at 25 ng/µl (Tsukuba Oligo Service Co., Ltd., Tsukuba, Japan). The
slides were hybridized at 46°C for 16 h in a moist chamber. After hybridization, the slides
were rinsed with warm hybridization buffer at 48°C and washed in pre-warmed washing
buffer (225 mM NaCl, 0.01% SDS, 20 mM Tris-HCl, pH 7.2) for 20 min at 48°C. The
washed slides were stained with DAPI (4', 6-diamidino-2-phenylindole dihydrochloride n-
hydrate) solution for 5 min at room temperature to stain the chromosomes as a control signal.
The slides were washed with distilled water for 5 min at room temperature and air-dried in the
dark. The dried slides were mounted with Vectashield (Vector Laboratories Inc., Burlingame,
Calif.) and examined under an Olympus BX50 epifluorescence microscope (Olympus
Corporation, Tokyo, Japan) equipped with a SenSys CCD camera (Photometrics Ltd., Tucson,
Ariz.) operated by the IPLab software (Scanalytics, Inc., Fairfax, Va.). DAPI and Cy3
signals were captured in pairs of ten to fifteen random microscopic fields (about 500 cells per
microscopic field). Hybridization images were manually counted and were colorized when
necessary using Adobe Photoshop 5.5 (Adobe Systems Incorporated, San Jose, Calif.).
Specific signals from the probes are represented as average percentages of the total cells
visualized by DAPI signals in the same microscopic field.

**Oligonucleotide probes.** The oligonucleotide probes and their target microorganisms
used in this study are shown in Table 1; the target region alignment of PBR2 and Bani449
(newly created in this study) is shown in Fig. 1. The computer alignment of 16S rRNA genes
from *Bifidobacterium* revealed that *B. animalis* and some other bifidobacteria are not targets of the probe Bif164 because the 16S rRNA sequence of these bacteria showed a single-base mismatch with Bif164 (27). The mismatched nucleotide (C or T) was replaced with Y to create a new probe designated Bif164m. No cross hybridizations was observed against non-target bacterial strains that include strains from *Lactobacillus, Clostridium, Bacteroides, Streptococcus* and *Enterococcus* (data not shown). In a preliminary experiment to visualize the secondary structures of the 16S rRNA of *B. breve* and *B. animalis* by computer simulation (GENETYX-Win, Software Development, Tokyo, Japan), it was found that the target regions for PBR2 and Bani449 were difficult to be accessed due to RNA-RNA interactions. Therefore, we used unlabeled oligonucleotides (helper probes), which were complimentary to the up- and downstream regions neighboring the probe target site on the 16S rRNA, to increase the target accessibility for the probes as suggested by Fuchs et al. (14). The sequences of these helper probes are also shown in Table 1. Indeed the hybridization efficiencies of PBR2 and Bani449 were significantly increased in both target strains by the application of these helper probes (data not shown).

**T-RFLP analysis.** To establish standard T-RF peak-sets for the identification of bacterial strains present in the cecal samples by T-RFLP analysis, T-RF lengths were determined for *B. breve* JCM 1192T and an indigenous rat strain *B. animalis* isolated from rat cecal samples using TOS Propionate Agar. Bacterial genomic DNA was extracted from pure cultures of these microorganisms and from pooled cecal samples of the four experimental groups (BD, RAF, CB, and RCB) using an Isoplant DNA Extraction Kit (Nippon Gene, Co., Ltd., Tokyo, Japan) according to the manufacturer’s instructions. Two replications of each sample were separately amplified by PCR and digested by restriction enzymes as described below. A PCR mixture was made from each sample using a GeneAmp PCR System 2400 (Applied Biosystems, Foster City, Calif.) with the 6-carboxyfluorescein (6-FAM)-labeled
primer 46F (5’-GCYTAACACATGCAAGTCGA-3’) (23), which was synthesized by Applied Biosystems Japan, and the unlabelled primer 1080R (5’-CCCAACATCTCAGACGAC-3’) (33). PCR conditions were based on the method described by Kaplan et al. (23) with modifications as follows: reaction mixture volume, 100 µl; template DNA, 200 ng; 1 x Gold buffer (Applied Biosystems); deoxynucleoside triphosphates, 0.6 mM; bovine serum albumin, 0.8 µg/l; MgCl₂, 3.5 mM; 6-FAM-labeled 46F primer, 0.2 µM; 1080R primer, 0.2 µM; and AmpliTaq Gold DNA polymerase, 4 U (Applied Biosystems). Reaction temperatures and the thermal cycling program for the fecal samples were as follows: 94°C for 2 min; 35 cycles of 94°C for 2 min, 48.5°C for 1 min, and 72°C for 1 min; with a final cycle of 72°C for 10 min. Amplified fragments were purified by SUPREC PCR (Takara Bio Inc., Otsu, Japan), and the purified fragments from three replications were pooled. Aliquots of about 1 µg of DNA in purified amplicon were digested with 10 U of each of HaeIII, HhaI, and MspI (Takara Bio Inc.) at 37°C for 24 h. The digestion reaction was stopped by incubation at 65°C in a water bath for 20 min followed by immediate cooling in an ice bath. The restriction digest products were subjected to ethanol precipitation and vacuum-dried. Fifty µl of distilled water was added to dissolve each dried sample. Aliquots of 1 µl of dissolved samples were then added to 10 µl mixture of formamide and size standard (GS 500 ROX, Applied Biosystems) (100:5, v/v). Each sample was denatured at 95°C for 2 min and then immediately placed on ice. The fluorescently labeled terminal restriction fragments (T-RFs) were analyzed by electrophoresis on an automatic sequence analyzer (ABI PRISM 3100, Applied Biosystems) in gene-scan mode, and the lengths of the T-RFs were determined by comparison with size standards using Genescan 3.7 software (Applied Biosystems).

Data analyses. The effects of diet on cecal organic acids and microbiota were analyzed separately by two-way ANOVA at P < 0.05 using JMP software (SAS Institute Inc., Cary, N.C.). The data obtained in T-RFLP analysis was processed according to Kaplan et al.
The T-RF peaks with areas less than the threshold value were excluded. The remaining T-RF peaks from three restriction enzymes were combined and examined by principal component analysis (PCA) using SPSS 10 software (SPSS Inc., Chicago, Ill.)

RESULTS

Carbon source preference of *B. breve* JCM 1192ᵀ. Prior to *in vivo* experiments, we have conducted growth experiments of *B. breve* JCM 1192ᵀ to characterize this bacterium in terms of carbon source preference. The results showed that *B. breve* JCM 1192ᵀ grew better on raffinose than other carbon sources tested as assessed by the $\mu$ value in MRS medium. The $\mu$ values measured (mean±SD, where n=2) on carbon sources tested were 0.45±0.02 (glucose), 0.65±0.02 (raffinose), and 0.64±0.08 (kesto), while sucrose and nystose were not at all assimilated by this strain. Therefore, raffinose was chosen as a prebiotic for this bacterium.

Animal experiments. All rats were healthy and alive until the day on which they were sacrificed. The pH value of the cecal contents of rats in the BD group (control) was significantly higher (8.1 ± 0.1) than those of rats in the RAF and RCB groups (6.8 ± 0.1 and 7.0 ± 0.2, respectively); the pH value of the cecal contents of CB rats was not different from that of BD rats (Table 2). Cecal samples from RAF and RCB rats were yellow; BD and CB cecal samples were brown-green. In addition, the cecal content weight of rats in the RAF and RCB groups were significantly greater than those of rats in the BD and CB groups (Table 2). To confirm the reproducibility of the results, we have conducted the second trial and obtained the similar results (data not shown).

As shown in Table 2, the amounts of lactic and acetic acids in RAF and RCB cecal samples were significantly higher than those in BD and CB cecal samples. However, the amounts of butyric, isovaleric, and valeric acids in the cecal samples from the RAF and RCB
groups were significantly lower than those in control samples due to the effect of raffinose in the diets. The amounts of propionic and succinic acids were significantly higher in CB and RCB, respectively, than those in BD.

**FISH analysis of microbiota in the cecal samples.** FISH was performed to enumerate the total and the target bacterial populations (Table 3). The total bacterial populations of each group were slightly different (ca. 1.74 – 2.19 x 10^{10} cells/g wet weight, DAPI signal), and the ratio of the total bacteria (probe Eub338) to the total cells (DAPI) was decreased from about 90% in the BD and CB groups to about 85% in the RAF and RCB groups. The cell morphologies of the predominant bacteria were different among the samples (Fig. 2). Long curved rods were the major forms in the BD and CB groups, while RAF and RCB samples contained short rods. The second trial gave the similar results (data not shown).

As shown in Table 3, at 23.9% of the total cell count, the *Clostridium coccoides* and *Eubacterium rectale* group (probe Erec482) represented the major proportion of the bacterial population in BD rats. The *Bacteroides* group (probe Bac303) made up 3.6% of the total population. As compared with BD (control) rats, RAF rats had a significantly lower number of targets for *Clostridium coccoides* and *Eubacterium rectale* group (12.9%). The *Lactobacillus* group (probe Lacb722) and bifidobacteria (probe Bif164m) accounted for 7.2% and 19.5%, respectively, of the total population. These proportions were significantly higher than those in BD rats (0.2% and 0.4%, respectively). Signals from *Clostridium histolyticum* group (probe Chis150) were slightly higher in RAF samples (1.2%) than in control samples (0.3%). RAF rats showed the highest proportion of streptococci and lactococci (probe Strc493) among all diet groups, although these bacteria did not account for more than 1.5% of the total population. CB rats showed no significant population differences from control rats, although the proportions of *Clostridium coccoides* and *Eubacterium rectale* group were slightly increased (29.7%). No *B. breve* (probe PBR2) signals were detected in CB rats even...
though the target strain was contained in the CB diet. RCB rats showed nearly the same proportion of *Clostridium coccoides* and *Eubacterium rectale* group (23.2%) and *Bacteroides* group (2.5%) as BD rats. The proportion of *Lactobacillus* group was higher in RCB rats (2.8%) than in BD rats (0.2%), but lower than in RAF rats (7.2%). A striking feature of the RCB group was the large proportion of bifidobacteria, which at 25.4% of the total DAPI-stained cells (corresponding to 29.4% of the total cell count using the probe Eub338) was the highest value of all the samples. *B. breve*, the administered bacterial strain, represented 6.3% of the total DAPI-stained cells (7.3% of total cell count using the probe Eub338) as detected using the PBR2 probe with its helpers. By the isolation of bifidobacteria using TOS Propionate Agar and 16S rRNA gene sequencing (data not shown), the bifidobacteria found in RAF rats and present in RCB rats along with *B. breve* JCM 1192T were shown to be *Bifidobacterium animalis*. In addition, a newly designed *B. animalis*-specific probe (probe Bani449) was used in this study. This species represented a significant proportion of the population, accounting 20.5% and 18.5% of the total populations in RAF and RCB rats, respectively. The second trial also gave the similar changes in the population of total bifidobacteria, *B. breve* and *B. animalis* confirming the reproducibility of the bifidobacterial responses (data not shown).

The increase in number of cells of the administered strain was strictly dependent on raffinose (Table 3). These results strongly support the synbiotic concept. Two-way ANOVA suggested that most of the alterations in the bacterial populations, particularly the increases in lactobacilli and bifidobacteria, were significantly influenced by the inclusion of raffinose in the diets.

**TRF analysis of cecal samples.** T-RF lengths of *B. animalis* isolated on TOS propionate agar from rat cecal samples and *B. breve* JCM 1192T were observed using three restriction enzymes as the standard T-RF peak-sets. *B. animalis* isolate resulted the observed
T-RF lengths of 28, 220 (HaeIII); 335 (HhaI); 38, 41, 95 (MspI), showing a slight difference from predicted values: 36, 220 (HaeIII); 334, 337 (HhaI); 45, 98 (MspI). The observed T-RF lengths of B. breve JCM 1192\textsuperscript{T} were 218 (HaeIII); 332 (HhaI); 93(MspI), whereas the predicted values were 219 (HaeIII); 333 (HhaI); 97 (MspI). Most of the experimentally determined T-RF lengths were within 4 bp of the predicted lengths, which was near to the shortest size of DNA standard used (GS 500 ROX). Similar phenomena have been reported (23, 36). The observed T-RF lengths of these strains contributed to the identification and the interpretation of the T-RF patterns from rat cecal samples.

By comparison with the T-RF peak-sets of the reference strains, presence of B. animalis was detected in the RAF and the RCB groups (Fig. 3). The T-RFLP electropherogram revealed that B. breve was present only in the RCB group and that it accounted for about 3.3 to 6.0% of the total peak area, as shown in Fig. 3. Although peak areas do not represent the actual population proportions of bacteria of interest, these data confirmed the existence of B. breve in the expected cecal samples.

According to the alignment of the T-RF peak-set, seven peak-sets were common to the four groups, although in different proportions. Approximately 29 peak-sets present in the control (BD) group were not found in the RAF or RCB groups; two of the indigenous peak-sets had relatively smaller areas in the BD group than in the RAF and RCB groups (data not shown). On the other hand, about 16 peak-sets were newly detected in the RAF and RCB groups, and two indigenous peak-sets had relatively greater areas than the corresponding peak-sets in the BD group (data not shown).

Then, we performed PCA, an advanced statistical technique, to reveal the variance-covariance structure of the T-RF patterns among all samples (Fig. 4). A total of 209 fragments from three restriction enzyme digests (HaeIII, 54 fragments; HhaI, 82 fragments; and MspI, 73 fragments) were included in the analysis. We found that the correlation of
variance was comprised of two principal components and the yield cumulative sum of squared
loading (variance) was 97.3%. The spots representing the RAF and RCB groups were
separated from the spots for the BD and CB groups on the PC1 axis (82.8%). This suggested
that the first principal component (PC1) separates samples based on the presence of raffinose
in the diet and constitutes a major factor in bacterial population alterations (Fig. 4). Spot of
the CB group was close to that of the BD group, while those of the RAF and RCB groups
were significantly separated from each other on the PC2 axis (14.5%). The second principal
component (PC2) appeared to separate samples based on the presence of \textit{B. breve} in RCB
group.

\textbf{DISCUSSION}

Rat/mouse intestinal microbiota consists of complex bacterial communities, which is
confirmed by culture methods and 16S rRNA gene clone library analyses (24, 37, 46). In
FISH analysis, we focused on \textit{Bacteroides}, \textit{Bifidobacterium}, \textit{Clostridium}, \textit{Eubacterium},
\textit{Lactobacillus}, and \textit{Streptococcus}, which are reported as the member of rat/mouse intestinal
microbiota (37, 38, 46). Six sets of genus/group-specific oligonucleotide probes identified
about 29-55\% of DAPI-stained cells and about 32-64\% of active bacterial cells (Eub338) in
the rat cecal communities (Table 3). The relatively high proportions of “unidentified
bacteria” (about 45-71\%) in Table 3 seemed to be due to the presence of large population of
uncharacterized bacterial group called “fusiform-shaped anaerobic bacteria” in murine
microbiota (10, 39). This group of bacteria is morphologically rather unique as being long
curved rods with sharp thin ends (39), and can be seen among microbial population in BD and
CB groups (Fig. 2ac).

The bifidobacteria were found to dominate the cecal microbial community in the RCB
(synbiotic) group (Table 3). The presence of \textit{B. breve} in this group was clearly demonstrated
by FISH analysis (Fig. 2d, Table 3), and was also confirmed by T-RFLP analysis (Fig. 3). Successful proliferation of administrated \textit{B. breve JCM 1192}\textsuperscript{T} observed in RCB group seems to be attributable to the availability of raffinose for \textit{B. breve JCM 1192}\textsuperscript{T} cells, because raffinose is not digested in rat intestine (17) and reach directly to cecum as the most preferable carbon source for this bacterium. The substantial increase of \textit{B. breve JCM 1192}\textsuperscript{T} cell number in the RCB group strongly demonstrated the effectiveness of the combination of raffinose and \textit{B. breve JCM 1192}\textsuperscript{T}.

Raffinose administration alone (RAF) appeared to induce a marked increase in indigenous bifidobacteria and lactobacilli (Table 3). This bifidobacteria was identified as \textit{B. animalis} by FISH and T-RFLP analyses. Although the presence of \textit{B. animalis} in rat intestine has been reported long time ago (40), the population of this bacterium in rat intestine has not been reported precisely. This study showed for the first time using molecular ecological methods that \textit{B. animalis} exists as a minor member in rat cecum (0.2%) and can be boosted up to about 20\% of the microbiota on raffinose administration. The increases in \textit{Bifidobacterium} and \textit{Lactobacillus} populations in RAF and RCB groups corresponded to the increased production of acetic and lactic acids and the decreased pH values of the cecal contents (Table 2).

Interestingly no proliferation of \textit{B. breve JCM 1192}\textsuperscript{T} was observed in CB group in contrast to RCB group (Table 3). This may be explained by the fact that this bacterium lacks the ability to utilize sucrose that is contained in large amounts in rat basal diet (602.5g/kg diet). On the other hand, \textit{B. breve} can utilize glucose and fructose (data not shown), which are the hydrolysate products of sucrose. Thus, we can also expect that there was a good chance for \textit{B. breve} to be fed by sucrose hydrolysate (glucose and fructose) in rat intestine. Since, we did not observe any proliferation of \textit{B. breve} cells in CB group, our results (\textit{B. breve}
proliferation observed only in RCB group) can illustrate the dependence of this strain upon administered prebiotic all the more clear owing to the inability of this strain to utilize sucrose.

FISH analysis can provide information on bacterial populations at the genus, group, and even species levels in terms of identification and enumeration (4). However, limited range of oligonucleotide probe set prevents us from obtaining whole picture of microbial population in rat cecum. Therefore, we performed PCA to distinguish the bacterial communities in the rat cecal contents based on T-RFs profiles (Fig. 4). The purpose of PCA is data reduction, which allows data interpretation through a few linear combinations of the original variables (treatments). PCA confirmed the differences of rat microbiota in CB and RCB based on T-RFLP profile. Composition of microbiota in CB was more similar to BD, indicating that probiotic administration only was not enough to modulate the bacterial population. When synbiotic was applied, the significant changes of bacterial population were observed along with the proliferation of *B. breve* as also confirmed by FISH analysis. These analyses led to the conclusion that application of synbiotic is necessary for the target strain, *B. breve* JCM 1192T, to proliferate in rat cecum.

Introduction of synbiotics concept by Gibson and Roberfroid (17) promoted the application of potential non-indigenous probiotic strain and its preferable carbon source to proliferate the administered strain in intestine. Several works published on the synbiotic application include modulation of intestinal microbiota (1, 7, 8, 32, 44), reduction of colon carcinogenesis (12, 16, 28) and protection from pathogen infection (6). Recently synbiotic therapy for the improvement of intestinal function (19, 20) or reduction of pathogenic bacteria (21, 22) has also been reported.

However, in many cases, demonstration of synbiotic effects seems not sufficient from microbiological point of view. One of the most important criteria for the evaluation of synbiotic effects is to monitor the proliferation of the administered probiotic bacteria at the
species level, which seems possible only by the application of molecular ecological methods for microbiota analysis. In most cases, however, culture-based methods were applied using selective-agar medium for counting the numbers of bacteria in fecal and cecal samples (6, 8, 28, 32, 44). Selective medium is sometimes not selective or too selective for target bacteria in microbiota analysis (5). Thus, the culture-based methods are not suitable to distinguish the administered bacteria from similar group of bacteria, thereby allowing only group-level analysis. In addition, it has been shown that only about 20-30% of microorganisms in human intestines are culturable (42). Hence, the reliability of the culture-based methods is judged to be rather low. Besides these technological obstacles, many studies lack control experiments such as probiotic or prebiotic alone (7, 19, 20, 21, 22, 32, 44), making the interpretation of the synbiotic results not conclusive.

In contrast to these previous reports, our work may provide the first clear demonstration of the microbiological aspects of the synbiotic effects in rat intestinal microbiota. First of all, we have quantitatively monitored the proliferation of administered strain at the species level and analyzed the other group of bacteria using FISH method. In addition, T-RFLP technique was applied to confirm FISH results and to compare whole microbiota between the experimental groups. These two molecular methods were applied for the first time to microbiota analysis in synbiotic experiment. As a potential probiotic we have employed *B. breve* JCM 1192T the carbon source utilization of which is well characterized. Analysis of complete set of treatment groups (BD, RAF, CB and RCB) was conducted. Organic acids as the indicator of the microbial activity were also analyzed. All these experimental design made precise analysis and interpretation of the obtained data possible.

Although complex nature of human diet, availability of raffinose in human intestine seems relatively low. Raffinose is found in food legumes at relatively high content (up to about 2%), but this amount was reduced significantly during food processing (34). Therefore,
supplementation of raffinose would be necessary to support the proliferation of administered

*B. breve* JCM 1192<sup>T</sup> also in human intestine, which will be evaluated in human trial.

ACKNOWLEDGEMENTS

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REFERENCES


23. **Kaplan, C. W., J. C. Astaire, M. E. Sanders, B. S. Reddy, and C. L. Kitts.** 2001. 16S ribosomal DNA terminal restriction fragment pattern analysis of bacterial communities in...


investigate bacteria of the phylum cytophaga-flavobacter-bacteroides in the natural
environment. Microbiology 142:1097-1106.

emerging method for characterizing diversity among homologous populations of

2003. Assessment of a new synbiotic preparation in healthy volunteers: survival,


Salunkhe and S. S. Kadam (ed.), CRC handbook of world food legumes: nutritional
chemistry, processing technology, and utilization, vol. 1. CRC Press, Inc., Boca Raton,
Florida.

laboratory rodents: final report of the American Institute of Nutrition ad hoc writing

of terminal RFLP analysis to characterize oral bacterial flora in saliva of healthy subjects

Bos. 2002. Analysis of 16S libraries of mouse gastrointestinal microflora reveals a large


FIG. 1. Alignment of probe sequences, their target sites, and the sequences of the corresponding sites in reference microorganisms of the large intestine (Type strains). Probe names are in accordance with the Oligonucleotide Probe Database nomenclature (2). N is an A/T/C/G wobble nucleotide.

FIG. 2. Epifluorescence images of bacterial cells from the four groups of rat cecal samples stained with DAPI (green) and hybridized with a *Bifidobacterium breve* species-specific oligonucleotide probe (PBR2) (red) in FISH analysis.

FIG. 3. Partial electropherogram of three restriction enzymes, *Hae*III, *Hha*I, *Msp*I-derived TRF profile from four rat cecal samples and two bifidobacteria. The size of each T-RF is indicated in base pairs along with the horizontal scale at the top the GeneScan results display.

FIG. 4. PCA of T-RFLP profiles from four groups of rat cecal samples. The percent variation accounted for each principal component is indicated in parentheses in the axis titles below and to the left, along with the principal component loading values.
# TABLE 1. 16S rRNA-targeted oligonucleotide probes used for the molecular analysis of rat cecal samples.

<table>
<thead>
<tr>
<th>Probe name (systematic name)</th>
<th>Probe sequence from 5′ to 3′</th>
<th>Target organism</th>
<th>Target site&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Source&lt;sup&gt;b&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Genus/group specific probe</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eub338 (S-D-Bact-0338-a-A-18)</td>
<td>GCTGCCTCCCGTAGGAGT</td>
<td>Bacteria</td>
<td>338</td>
<td>3</td>
</tr>
<tr>
<td>Erec482 (S-*.Erec-0482-a-A-19)</td>
<td>GCTTCTTAGTGACGGGTGACCC</td>
<td>Eubacterium rectale</td>
<td>482</td>
<td>13</td>
</tr>
<tr>
<td>Chis150 (S-*.Clos-0150-a-A-23)</td>
<td>TTATGCATTTGATATATCTT</td>
<td>Clostridium histolyticum group</td>
<td>150</td>
<td>13</td>
</tr>
<tr>
<td>Bac303 (S-G-Bac-0303-a-A-17)</td>
<td>CCAATGTGGGGGACCTT</td>
<td>Bacteroides group</td>
<td>303</td>
<td>30</td>
</tr>
<tr>
<td>Lacb722 (S-G-Lacb-0722-a-A-25)</td>
<td>YACCCGCTACACATGRAGTTCCACT</td>
<td>Lactobacillus group</td>
<td>722</td>
<td>41</td>
</tr>
<tr>
<td>Stre493 (S-*.Strc-0493-a-A-19)</td>
<td>GTTAGCCGTCCTTCTCTG</td>
<td>Streptococci and lactococci</td>
<td>493</td>
<td>13</td>
</tr>
<tr>
<td>Bif164m (S-G-Bif-0164-b-a-A-18)</td>
<td>CATCCGYYATTACCAACC</td>
<td>Bifidobacterium spp.</td>
<td>164</td>
<td>This work&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>Species/strain specific probe</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PBR2 (S-S-Pbr2-0182-a-A-19)</td>
<td>CCATGCGGTGTGATGGAGC</td>
<td>Bifidobacterium breve</td>
<td>182</td>
<td>43</td>
</tr>
<tr>
<td>Bani433 (S-S-Bani-0449-a-A-21)</td>
<td>CACTCAACACCGCCCGAAGCC</td>
<td>Bifidobacterium animalis JCM 1190&lt;sup&gt;T&lt;/sup&gt;</td>
<td>449</td>
<td>This work&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>Non labeled oligonucleotides (helpers)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PBR2-1&lt;sup&gt;st&lt;/sup&gt;-Upper helper</td>
<td>ATCCGCATTACCACCCGT</td>
<td>Bifidobacterium breve</td>
<td>163</td>
<td>This work</td>
</tr>
<tr>
<td>PBR2-1&lt;sup&gt;st&lt;/sup&gt;-Lower helper</td>
<td>CAAAGGGCTTACCCCAAACA</td>
<td>Bifidobacterium breve</td>
<td>201</td>
<td>This work</td>
</tr>
<tr>
<td>PBR2-2&lt;sup&gt;nd&lt;/sup&gt;-Upper helper</td>
<td>TATCCAGGAGCTATTCGGGT</td>
<td>Bifidobacterium breve</td>
<td>144</td>
<td>This work</td>
</tr>
<tr>
<td>PBR2-2&lt;sup&gt;nd&lt;/sup&gt;-Lower helper</td>
<td>GCGACCCCATCCCGG</td>
<td>Bifidobacterium breve</td>
<td>220</td>
<td>This work</td>
</tr>
<tr>
<td>Bani433-1&lt;sup&gt;st&lt;/sup&gt;-Upper helper</td>
<td>GTGCCCTTGCCCTTGAAACAAA</td>
<td>Bifidobacterium animalis JCM 1190&lt;sup&gt;T&lt;/sup&gt;</td>
<td>428</td>
<td>This work</td>
</tr>
<tr>
<td>Bani433-1&lt;sup&gt;st&lt;/sup&gt;-Lower helper</td>
<td>CGGTGTATTATCCGAAATC</td>
<td>Bifidobacterium animalis JCM 1190&lt;sup&gt;T&lt;/sup&gt;</td>
<td>470</td>
<td>This work</td>
</tr>
</tbody>
</table>

<sup>a</sup> Positions in *E. coli* 16S rRNA.

<sup>b</sup> Reference number.

<sup>c</sup> Bif164m was modified from Bif164 reported by Langendijk et al. (27) by changing the eighth 5′-nucleotide from C to Y.

<sup>d</sup> Newly designed in this investigation.
TABLE 2. Characterization of rat cecal samples: organic acids produced, cecal contents weight, and pH value and two-way ANOVA.

<table>
<thead>
<tr>
<th>Organic Acids</th>
<th>Amount of organic acids (μmol/g cecal content)</th>
<th>Two-way ANOVA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1. BD</td>
<td>2. RAF</td>
</tr>
<tr>
<td>Lactate</td>
<td>ND</td>
<td>16.8 (5.8)</td>
</tr>
<tr>
<td>Acetate</td>
<td>42.1 (5.7)</td>
<td>54.3 (6.7)</td>
</tr>
<tr>
<td>Propionate</td>
<td>9.4 (1.0)</td>
<td>11.1 (0.7)</td>
</tr>
<tr>
<td>Butyrate</td>
<td>9.3 (2.2)</td>
<td>3.4 (1.0)</td>
</tr>
<tr>
<td>Succinate</td>
<td>26.7 (5.1)</td>
<td>21.2 (6.1)</td>
</tr>
<tr>
<td>Isovalerate</td>
<td>1.0 (0.3)</td>
<td>0.1 (0.1)</td>
</tr>
<tr>
<td>Valerate</td>
<td>1.6 (0.1)</td>
<td>0.4 (0.2)</td>
</tr>
<tr>
<td>Cecal contents weight (g)</td>
<td>1.21 (0.09)</td>
<td>2.13 (0.09)</td>
</tr>
<tr>
<td>Cecal contents pH</td>
<td>8.1 (0.1)</td>
<td>6.8 (0.1)</td>
</tr>
</tbody>
</table>

\(a\) Values are expressed as means (SEM), n = 6. BD represents basal diet with crystalline cellulose (50 g/kg diet), RAF represents BD supplemented with raffinose (30 g/kg diet), CB represents BD supplemented with gelatin-encapsulated B. breve (30 g/kg diet), and RCB represents BD supplemented with raffinose (30 g/kg diet) and encapsulated B. breve (30 g/kg diet).

\(b\) ND, not detected.

\(c\) NS, not significant.

* Significantly different (\(p<0.05\)).

28
TABLE 3. Characterization of rat cecal microbiota based on FISH analysis: Number of bacterial cells per gram, percentage of total microbiota, and two-way ANOVA.

<table>
<thead>
<tr>
<th>Population</th>
<th>Stain or probe</th>
<th>1. BD (control)</th>
<th>2. RAF</th>
<th>3. CB</th>
<th>4. RCB</th>
<th>Two-way ANOVA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total cells</td>
<td>DAPI</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Total bacteria</td>
<td>Eub338</td>
<td>89.6 (1.5)</td>
<td>84.4 (1.4)</td>
<td>90.4 (0.8)</td>
<td>86.3 (1.3)</td>
<td>*     NS&lt;sup&gt;c&lt;/sup&gt; NS</td>
</tr>
<tr>
<td>Clostridium cocoides and Eubacterium rectale group</td>
<td>Erec482</td>
<td>23.9 (2.7)</td>
<td>12.9 (3.3)</td>
<td>29.7 (4.0)</td>
<td>23.2 (5.8)</td>
<td>*     *     NS</td>
</tr>
<tr>
<td>Clostridium histolyticum group</td>
<td>Chis150</td>
<td>0.3 (0.1)</td>
<td>1.2 (0.4)</td>
<td>0.1 (0.0)</td>
<td>1.2 (0.4)</td>
<td>*     *     *</td>
</tr>
<tr>
<td>Bacteroides group</td>
<td>Bac303</td>
<td>3.6 (1.4)</td>
<td>2.1 (0.6)</td>
<td>0.9 (0.2)</td>
<td>2.5 (1.1)</td>
<td>NS     NS     *</td>
</tr>
<tr>
<td>Lactobacillus group</td>
<td>Laeb722</td>
<td>0.2 (0.0)</td>
<td>7.2 (1.1)</td>
<td>0.8 (0.2)</td>
<td>2.8 (0.6)</td>
<td>*     *     *</td>
</tr>
<tr>
<td>Streptococci and lactococci</td>
<td>Strec493</td>
<td>0.5 (0.2)</td>
<td>1.5 (0.9)</td>
<td>0.8 (0.4)</td>
<td>0.3 (0.2)</td>
<td>NS     NS     NS</td>
</tr>
<tr>
<td>Bifidobacterium spp.</td>
<td>Bif164m</td>
<td>0.4 (0.2)</td>
<td>19.5 (4.8)</td>
<td>0.3 (0.1)</td>
<td>25.4 (4.6)</td>
<td>*     NS     NS</td>
</tr>
<tr>
<td>Unidentified bacteria</td>
<td>none</td>
<td>71.1</td>
<td>55.6</td>
<td>67.4</td>
<td>44.6</td>
<td></td>
</tr>
<tr>
<td>Bifidobacterium breve</td>
<td>PBR2</td>
<td>ND&lt;sup&gt;b&lt;/sup&gt;</td>
<td>ND</td>
<td>ND</td>
<td>6.3 (1.9)</td>
<td>*     *     *</td>
</tr>
<tr>
<td>Bifidobacterium animalis</td>
<td>Bani449</td>
<td>0.2 (0.1)</td>
<td>20.5 (2.2)</td>
<td>0.1 (0.0)</td>
<td>18.5 (2.7)</td>
<td>*     NS     NS</td>
</tr>
<tr>
<td>Number of cells/g cecal contents&lt;sup&gt;d&lt;/sup&gt;</td>
<td></td>
<td>1.90 (0.9)×10&lt;sup&gt;10&lt;/sup&gt;</td>
<td>1.74 (0.5)×10&lt;sup&gt;10&lt;/sup&gt;</td>
<td>2.06 (0.4)×10&lt;sup&gt;10&lt;/sup&gt;</td>
<td>2.19 (0.3)×10&lt;sup&gt;10&lt;/sup&gt;</td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup> Average percentage of the total cells visualized by DAPI signals in the same microscopic field. Values are expressed as means (SEM), n = 6.

<sup>b</sup> ND, not detected.

<sup>c</sup> NS, not significant.

<sup>d</sup> Wet weight value are expressed as means (SEM), n=6.

* Significantly different (p<0.05).
PBR2  
(S-S-Pbr2-0182-a-A-19)  
Target  
3’ CGAGGTAGTGTTGGCGTACC 5’ 
5’ GCTCCATCACACCCGCATGG 3’ 

Bifidobacterium breve  
Bifidobacterium longum  
Bifidobacterium infantis  
Bifidobacterium adolescentis  
Bacteroides ovatus  
Lactobacillus acidophilus  
Lactobacillus salivarius  
Clostridium innocuum  
Enterococcus faecalis  
Eubacterium aerofaciens  
Ruminococcus productus  

Bani449  
(S-S-Bani-0449-a-A-21)  
Target  
3’ CGAAGCCCCGCAAACTCAG 5’ 
5’ GGCTTCGGGCCGTGTTGAGTG 3’ 

Bifidobacterium animalis  
Bifidobacterium pseudolongum  
Bifidobacterium lactis  
Bifidobacterium adolescentis  
Bifidobacterium breve  
Bacteroides vulgatus  
Bacteroides distasonis  
Lactobacillus acidophilus  
Lactobacillus salivarius  
Clostridium clostridiiforme  
Clostridium cocleatum  
Enterococcus faecalis  
Ruminococcus productus  

FIG 1. Dinoto et al
FIG 3. Dinoto et al
PC1 (82.8%) vs. PC2 (14.5%)

RAF

BD

RCB

FIG 4. Dinoto et al