A meta-analysis of the effects of feed additives on ruminal pH and A/P ratio :a potential for reducing the risk of subacute ruminal acidosis (SARA)

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Subacute ruminal acidosis (SARA)

- 주로 농후사료를 과다 급여하는 반추동물에게 흔하게 나타나는 질병 (Calsamiglia et al., 2012)
- 고능력우의 20-40%가 SARA를 겪고 있음(Kleen, 2004)
- 미국의 경우, SARA로 유량의 감소, 조기도태, 2차 질병 증가 등으로 인한 손실은 1.12 $/day/cow 정도도 예상됨(Stone, 1999)

Calsamiglia, S., M. Blanch, A. Ferret, and D. Moya. 2012. Is subacute ruminal acidosis a pH related problem? Causes and tools for its control. Anim. Feed Sci. Technol. 172:42–50.
Kleen, J.L., 2004. PhD Thesis: prevalence of subacute ruminal acidosis in Dutch dairy herds – a field study. Tierärztliche Hochschule Hannover, Germany.
Stone, W.C., 1999. The effect of subclinical rumen acidosis on milk components. In: Proceedings of the Cornell Nutrition Conference of Feed Manufacturers, Syracuse, N.Y. Cornell University, Ithaca, NY, USA, pp. 40–46.

Subacute ruminal acidosis (SARA)

주요증상

- 섭취량/사료효율/유지방 감소
- 제엽염(laminitis)
- 간농양(liver abscesses)
- 분내 알곡 발견/설사
- 심한 경우 사망까지 이를 수 있음

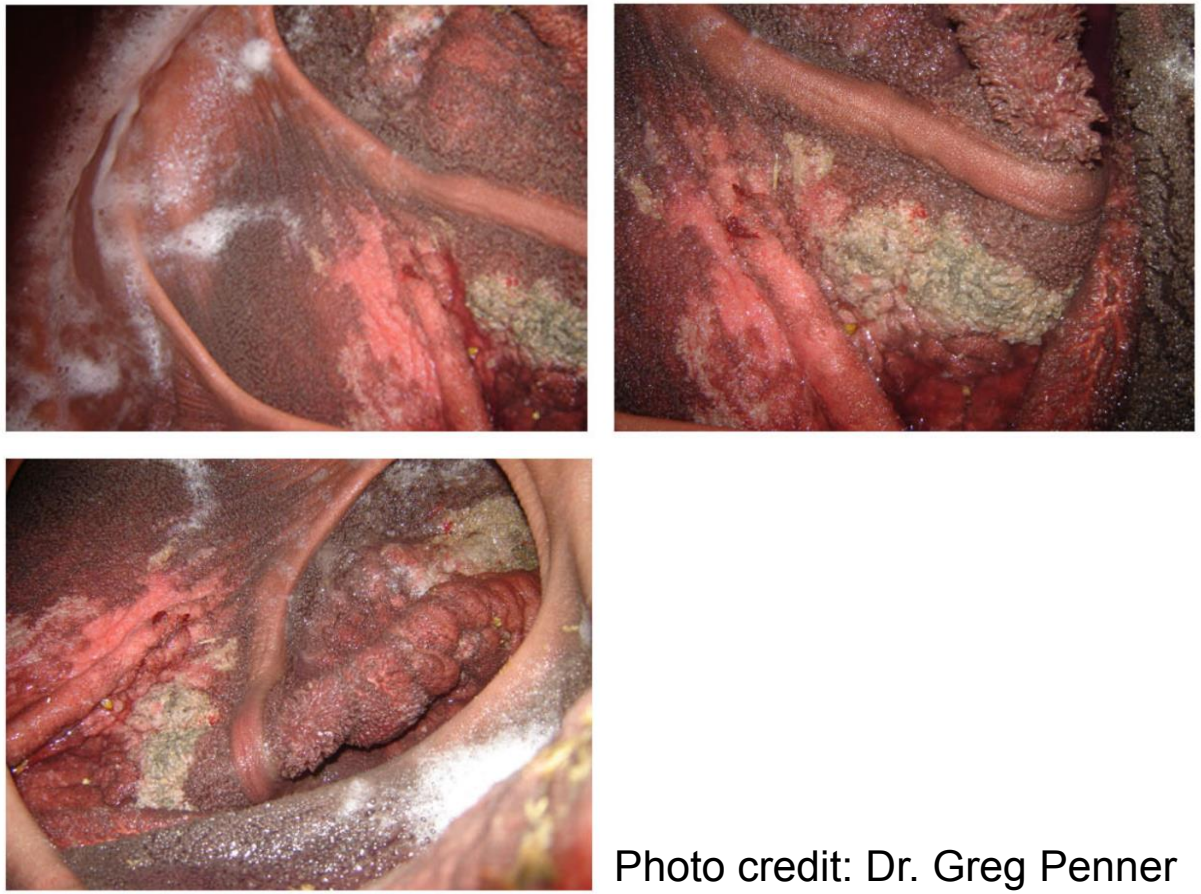


Photo credit: Dr. Greg Penner

Subacute ruminal acidosis (SARA)

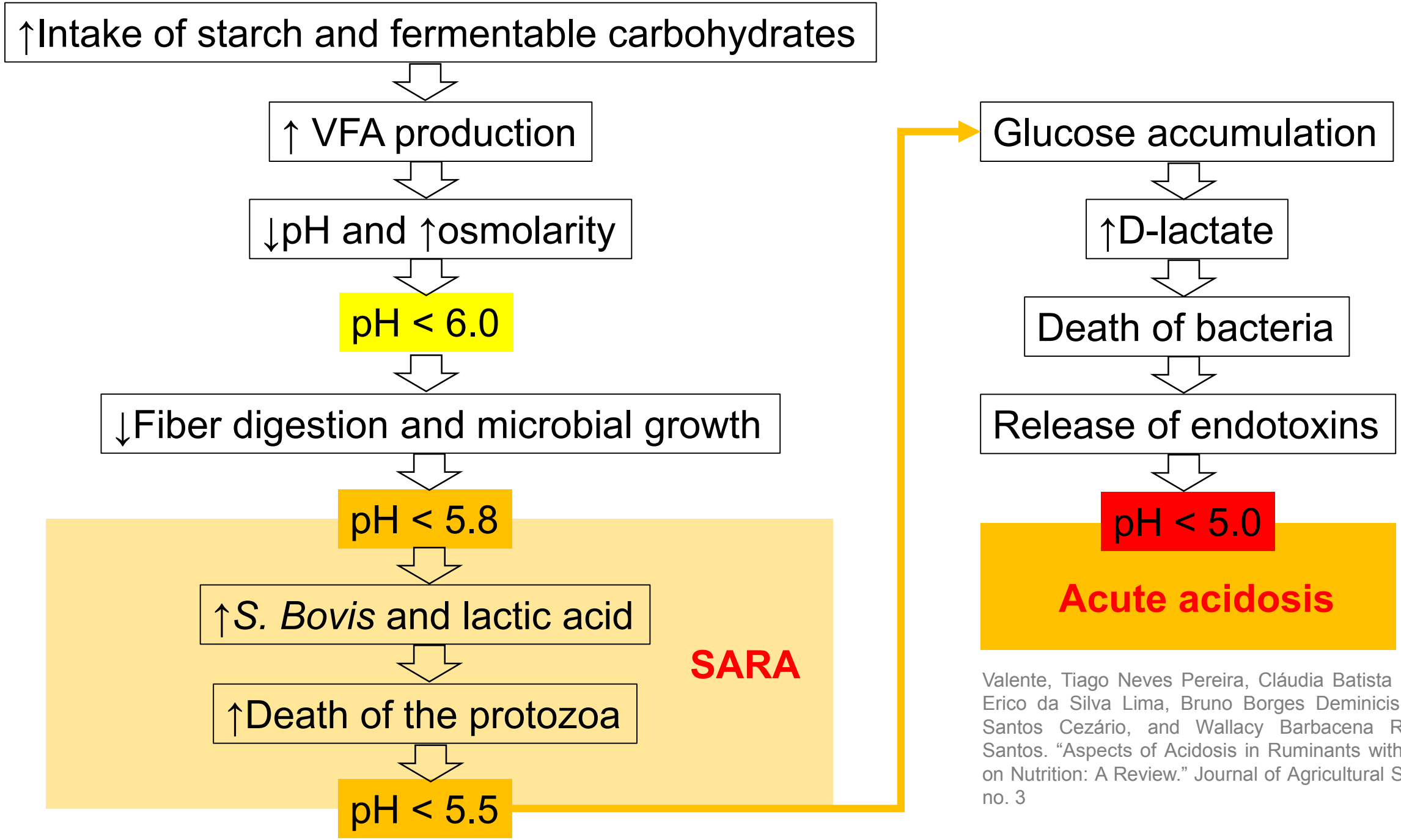
주요원인

- 농후사료의 과다 급여

  *"We propose that SARA should be redefined as a "**high-concentrate syndrome**" because it includes both the changes in pH and the effect of type of diet" (Calsamiglia et al., 2012)*

- 이유/질병/분만 이후 사료의 급격한 변화
- 전환기/비유초기의 잘못된 사양관리

Calsamiglia, S., M. Blanch, A. Ferret, and D. Moya. 2012. Is subacute ruminal acidosis a pH related problem? Causes and tools for its control. Anim. Feed Sci. Technol. 172:42–50.



Valente, Tiago Neves Pereira, Cláudia Batista Sampaio, Erico da Silva Lima, Bruno Borges Deminicis, Andréia Santos Cezário, and Wallacy Barbacena Rosa dos Santos. “Aspects of Acidosis in Ruminants with a Focus on Nutrition: A Review.” Journal of Agricultural Science 9, no. 3

Subacute ruminal acidosis (SARA)

어떻게 해야 하나?

- 일반적으로 반추위 pH를 높이는 것이 중요하다고 생각
- 하지만 반추위 pH가 5.5보다 높아도 SARA가 발생할 수 있음
  또한 낮다고 100% 발생하는 것도 아님
- 따라서 1) 반추위 pH 조절과 함께 2) 반추위 미생물 컨트롤을
  모두 고려한 접근이 필요함

PARADOX

Productivity vs. **Health & welfare**

두마리 토끼를 다 잡을 순 없을까?

Subacute ruminal acidosis (SARA)

예방 및 치료

- Effective fiber를 충분히 급여
- Ionophores 급여
- ~~항생제 급여~~
- 완충제 급여 (e.g. bicarbonate)
- 효모제/생균제 급여
- 사료급여 횟수 증가

Meta-analysis

메타분석

- 동일한 주제에 대한 **다양한** 연구결과를
  체계적이고 **계량적**으로 분석하는 분석 방법
- 특정한 한 연구의 결과에만 의존해서 결론을 내릴 경우 -> 잘못된 결정의 위험 ↑
- 연구결과는 연구마다 상충되거나 다를 수 있음

Meta-analysis

메타분석의 단계

1. 연구 주제 선정/질문 제기
2. 문헌검색
3. 데이터 추출 및 코딩
4. 데이터 분석: 효과크기 계산/동질성 검증/출판편향 검증
5. 결과 보고서 작성

Materials and methods

연구 목적

- 각종 첨가제(bicarbonate, yeast culture, essential oil 및 organic acid)가 반추위 발효 안정화를 위해 쓰이나 각각의 효과의 크기에 대한 종합적이고 계량적인 연구가 없음
- 따라서 본 연구에서는 meta-analysis를 통해 각종 사료 첨가제가 반추위 pH 및 A/P ratio에 미치는 영향을 조사하고, 이를 통해 SARA를 예방 및 치료할 수 있는 가능성을 알아보고자 함

Materials and methods

문헌 검색

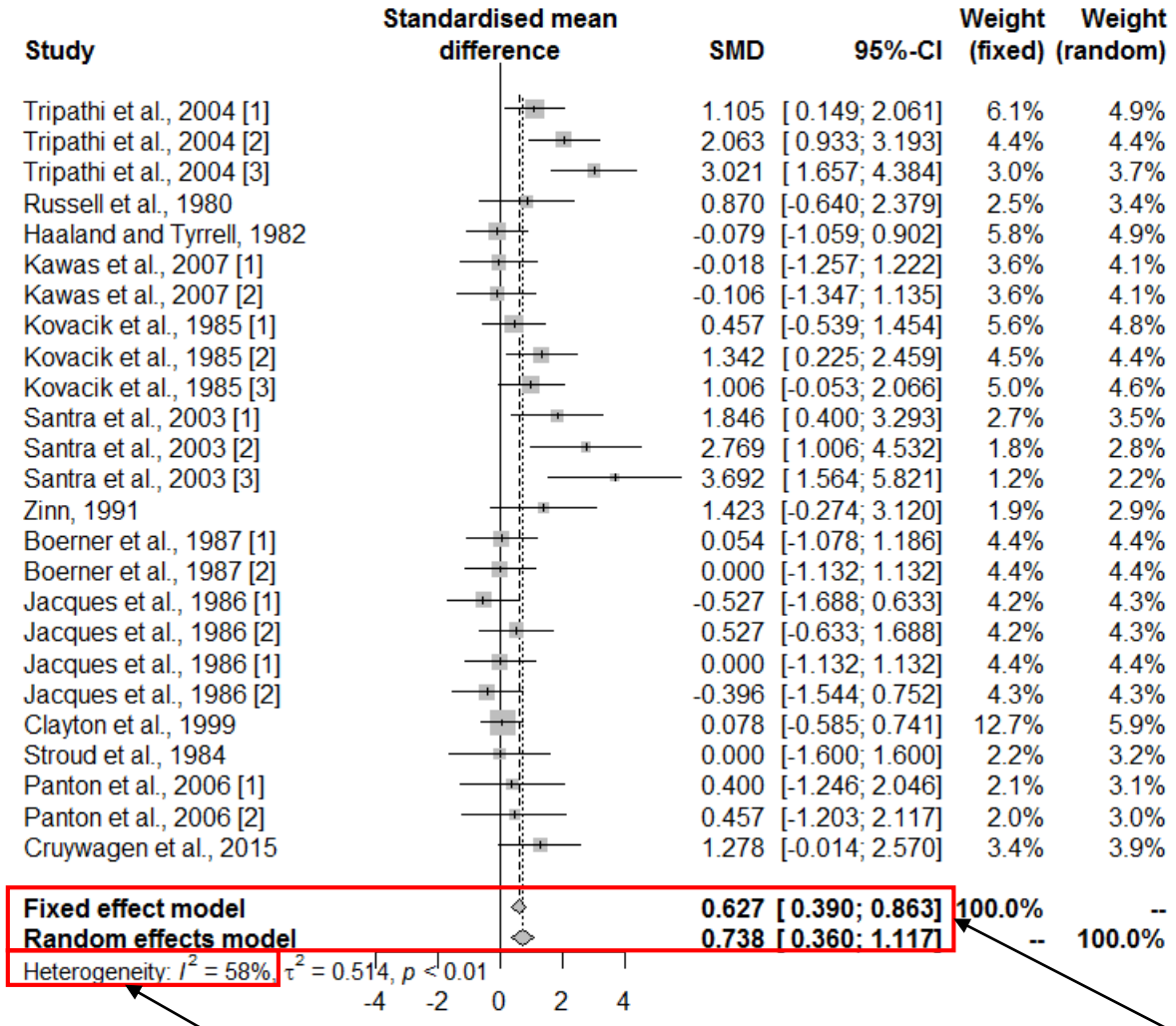
- Google scholar 및 Science direct를 이용
- Peer-review가 수행된 연구 자료만 수집
- Keywords: sodium bicarbonate; sodium sesquicarbonate; yeast culture; essential oil; malic acid
- Target response: rumen pH 및 acetate to propionate ratio
- 총 41개의 연구 84개의 데이터셋이 사용됨

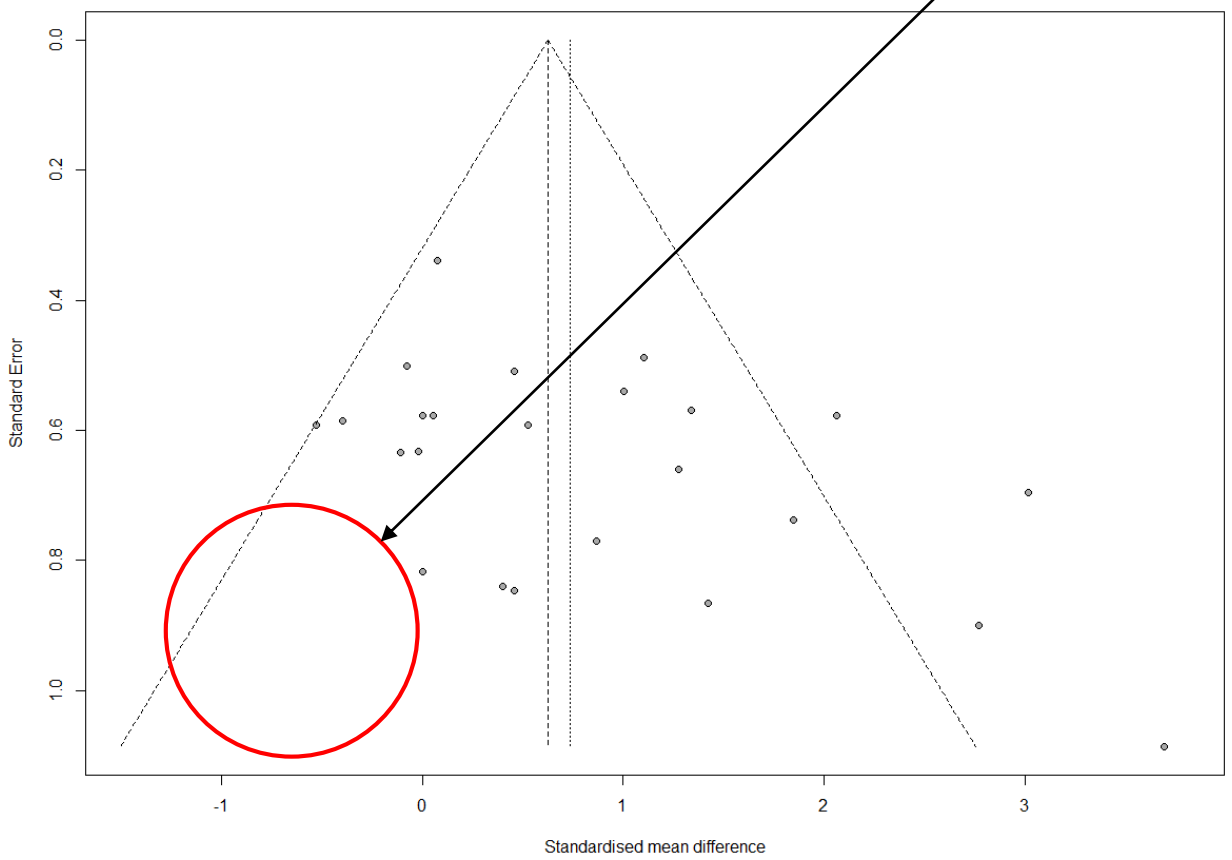
Materials and methods

통계 분석

- 통계분석은 R software (version 3.4.0)의 Meta package를 이용하여 분석
- Standardized mean difference (SMD; a.k.a Effect size)를 계산
- SMD의 이질성(heterogeneity)은 tau square (T^2) 및 I square (I^2)를 이용하여 계산
- 이질성이 높을 경우 meta-regression 및 Meta-ANOVA 분석을 수행
- 출판편향(publication bias) 분석을 위해 funnel plot test를 수행

Results: sodium bicarbonate (pH)

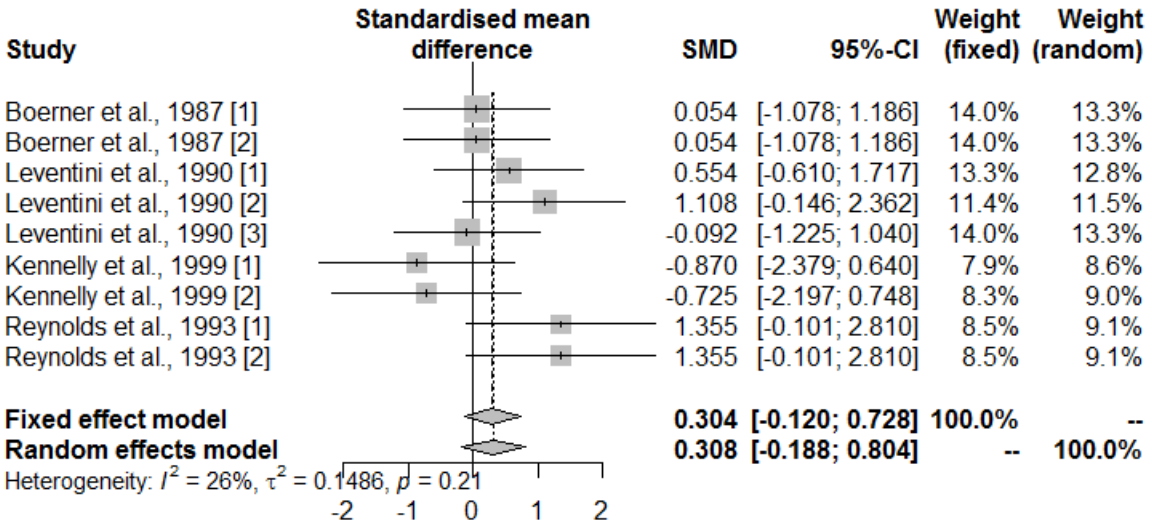


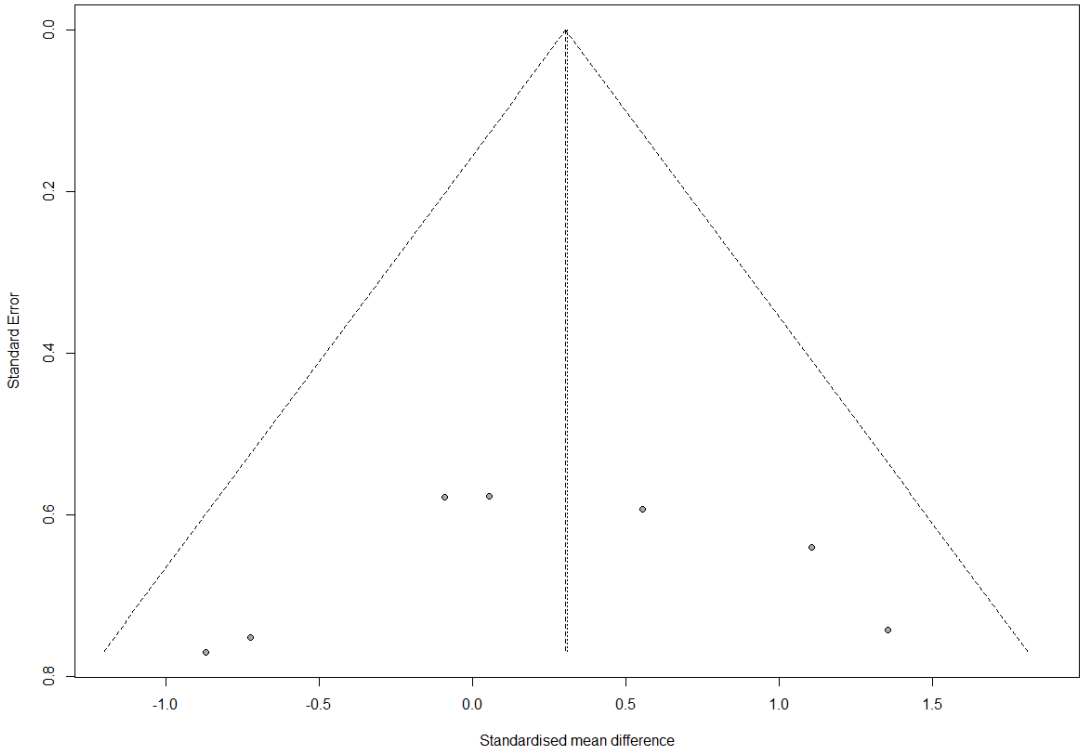


An I^2 value less than 25% indicated low heterogeneity, whereas values between 35 to 50% denoted moderate heterogeneity and those above 50% denoted high heterogeneity (Higgins et al., 2003).

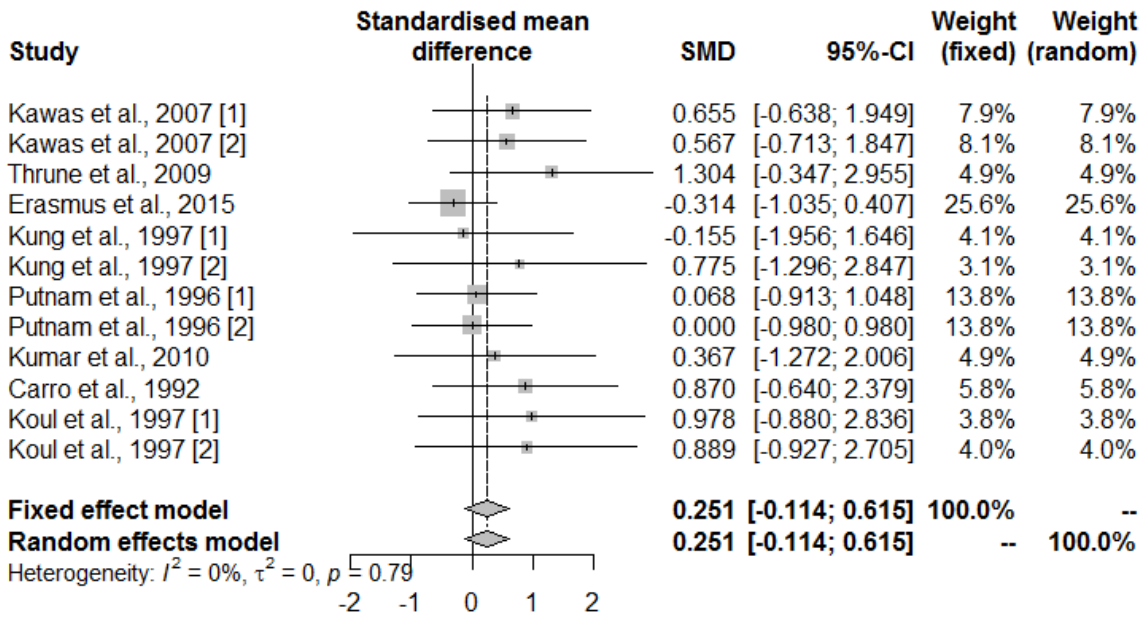
Standardized mean difference values of < 0.2, > 0.2 and < 0.7, or > 0.8 were considered small, moderate, or large effects, respectively (Cohen, 1988).

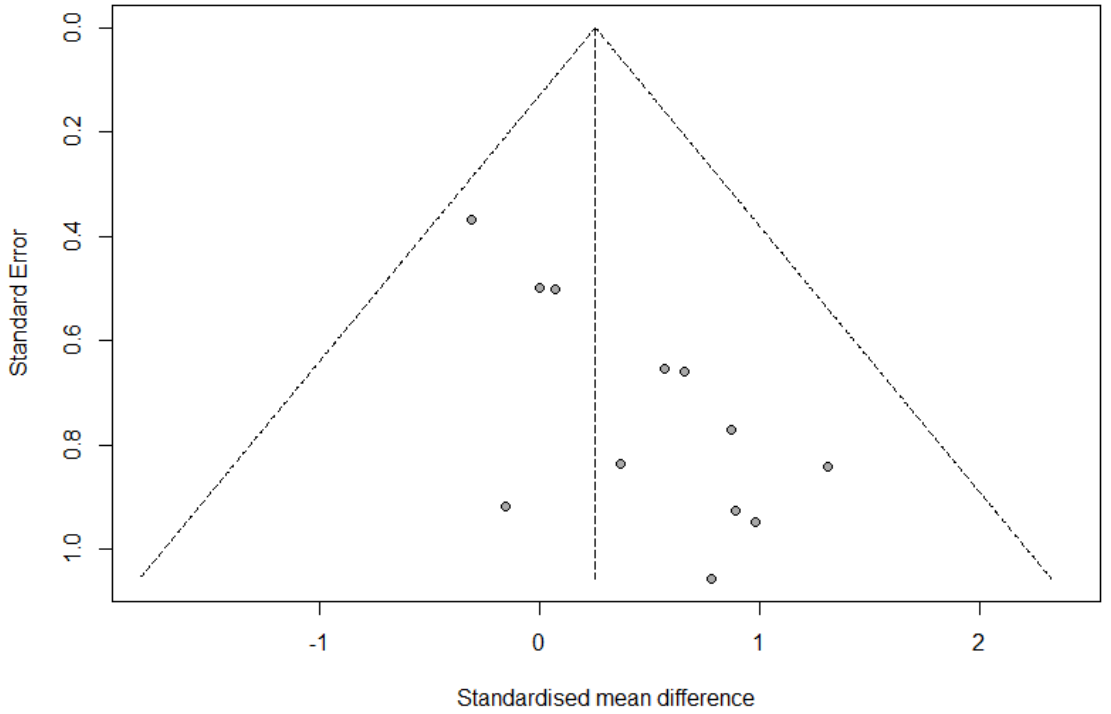
Results: sodium sesquicarbonate (pH)



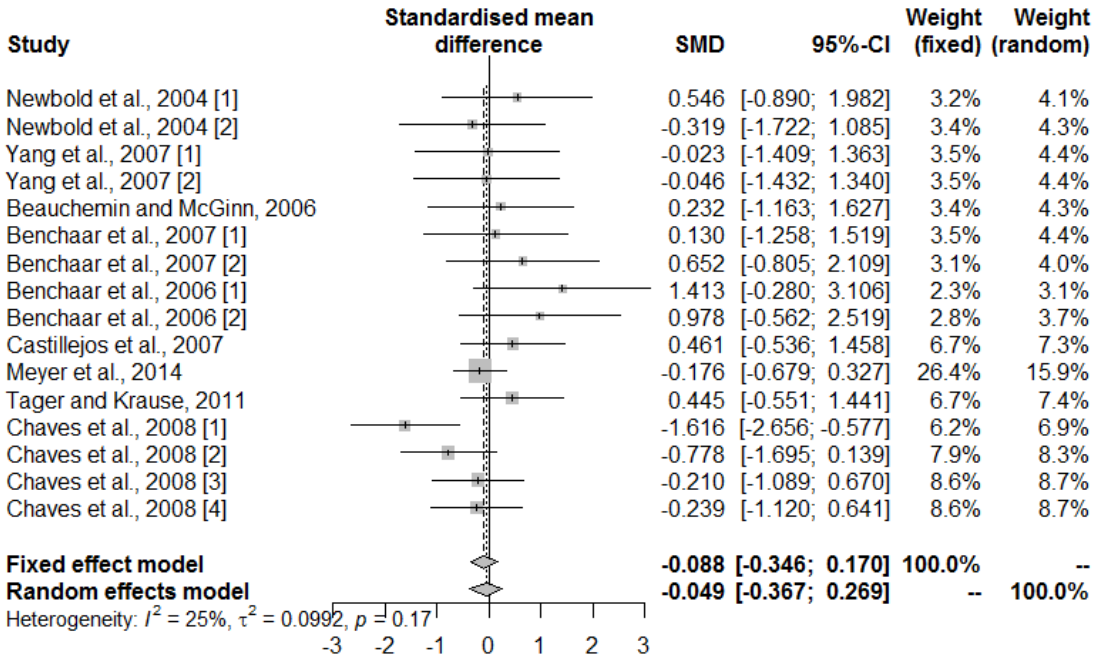


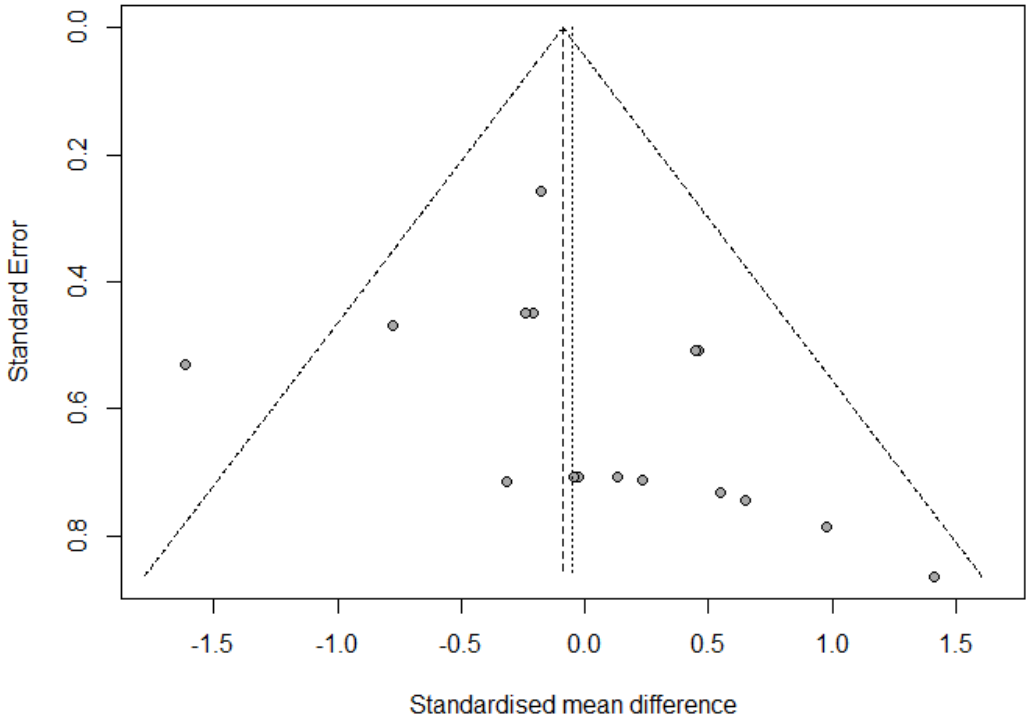
Results: yeast culture (pH)



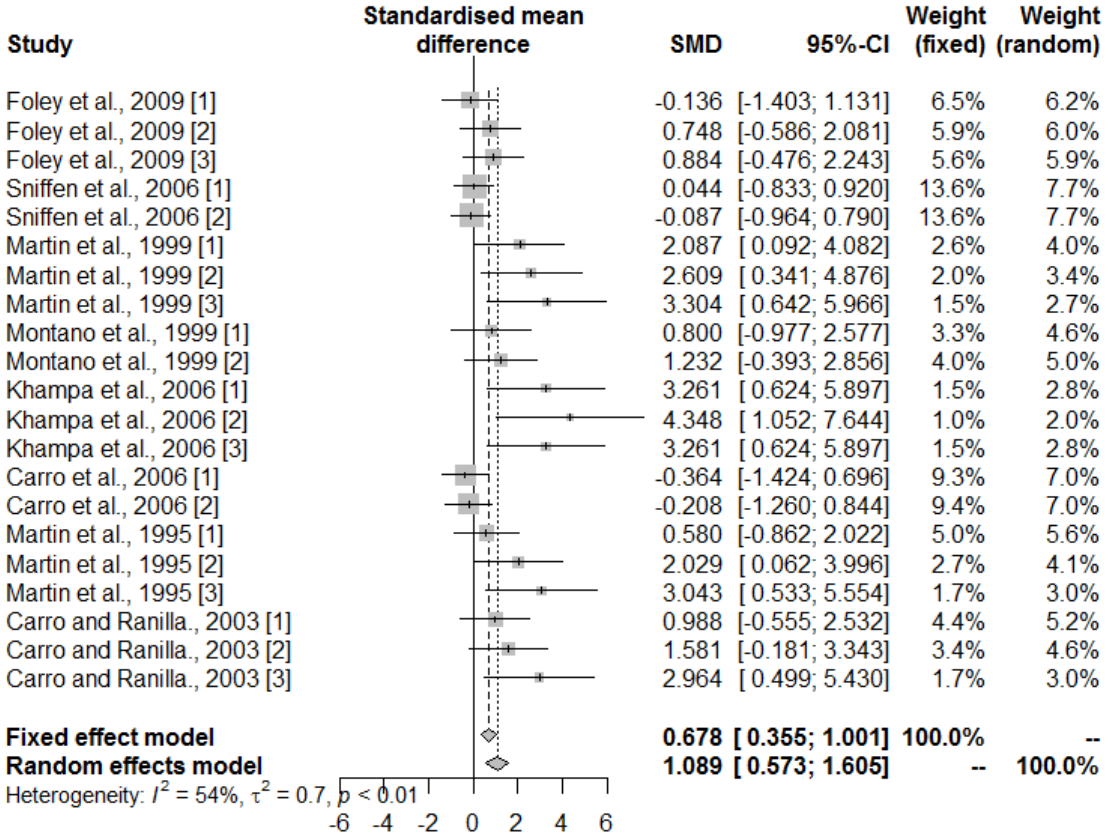


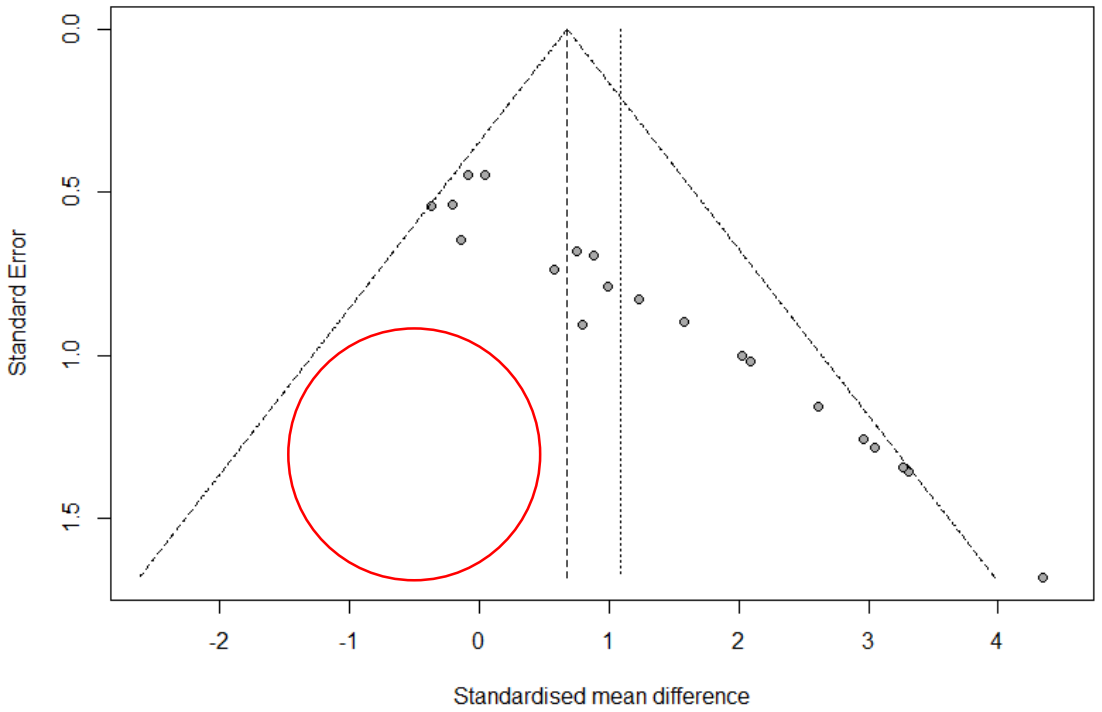
Results: essential oil (pH)



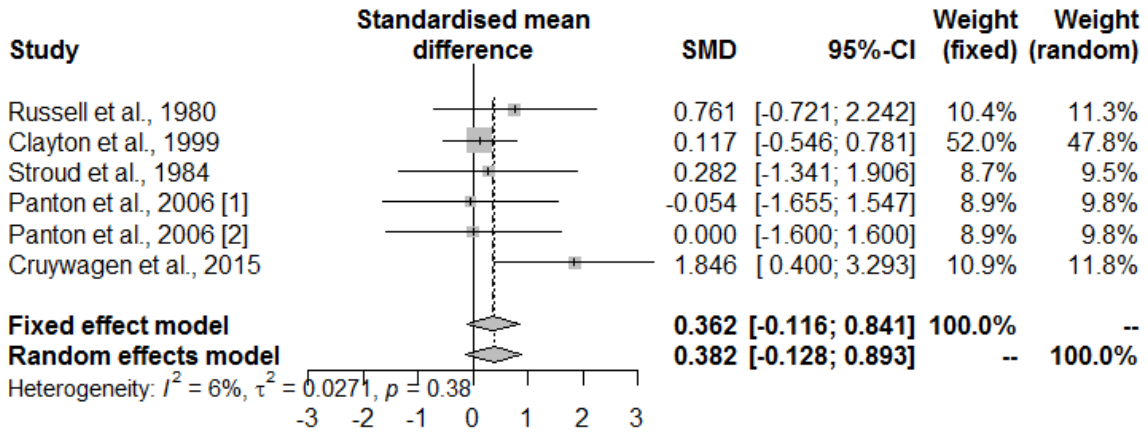


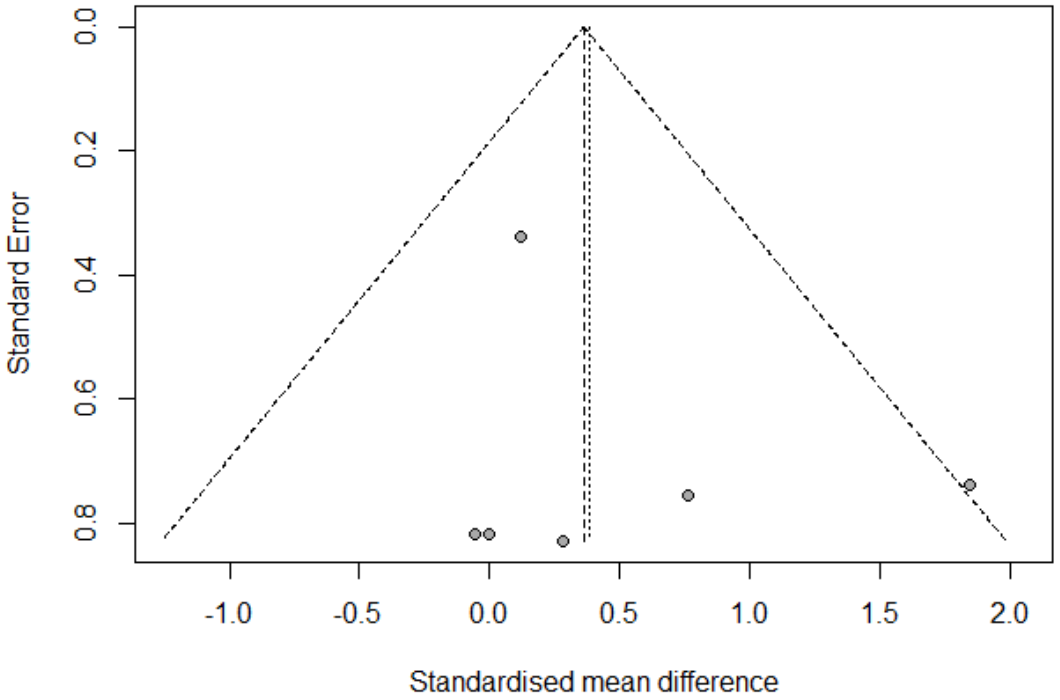
Results: malic acid (pH)



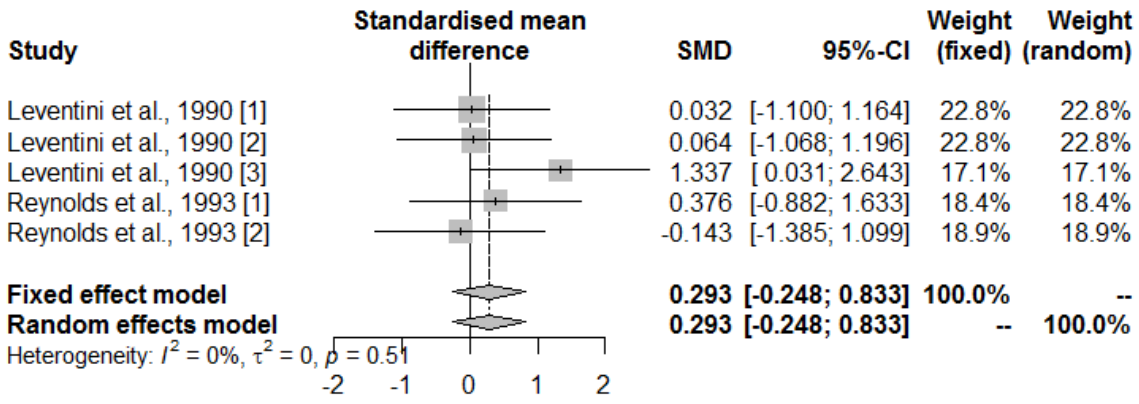


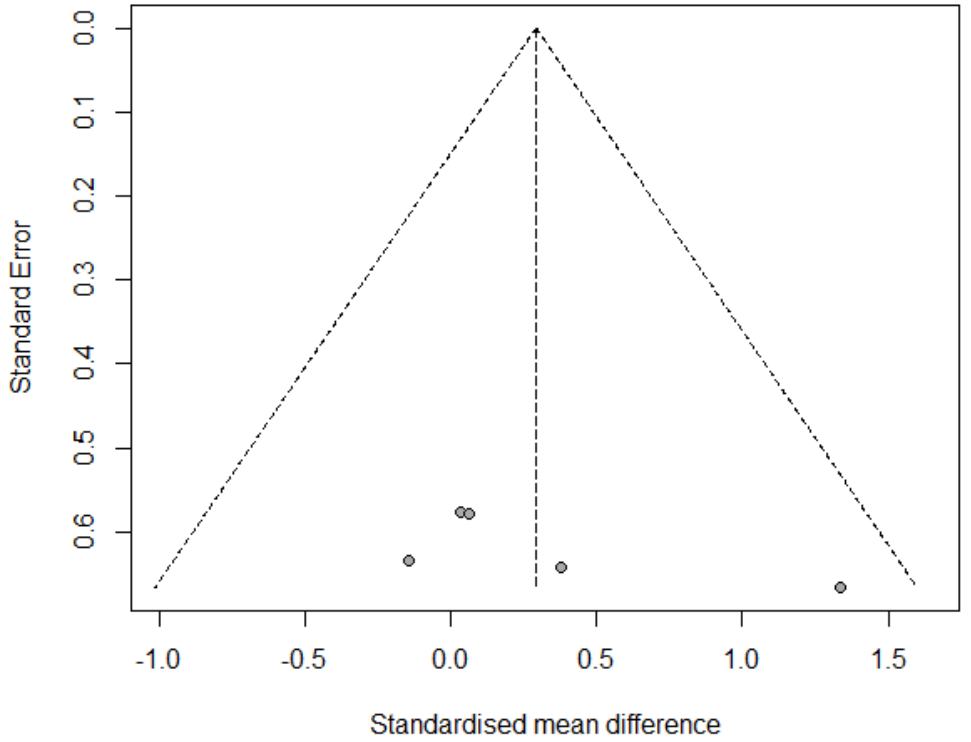
Results: sodium bicarbonate (A/P ratio)



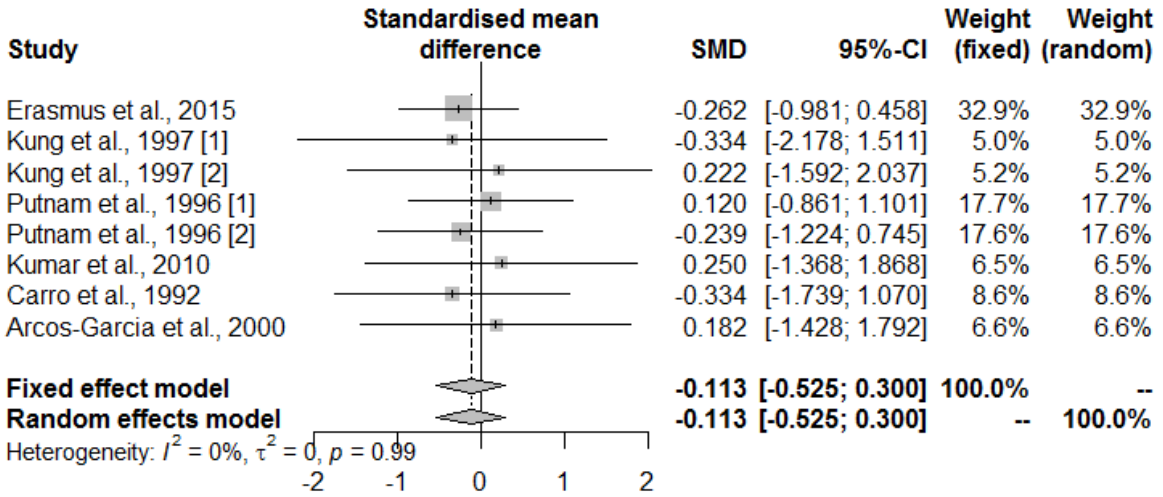


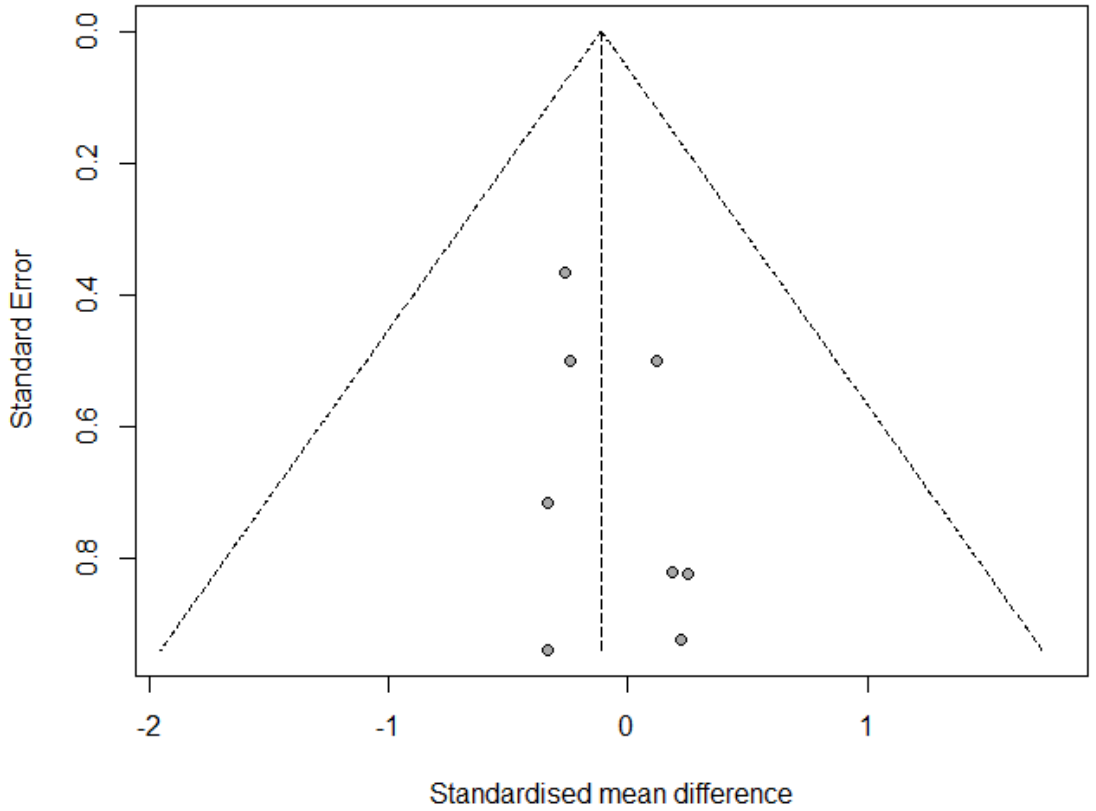
Results: sodium sesquicarbonate (A/P ratio)



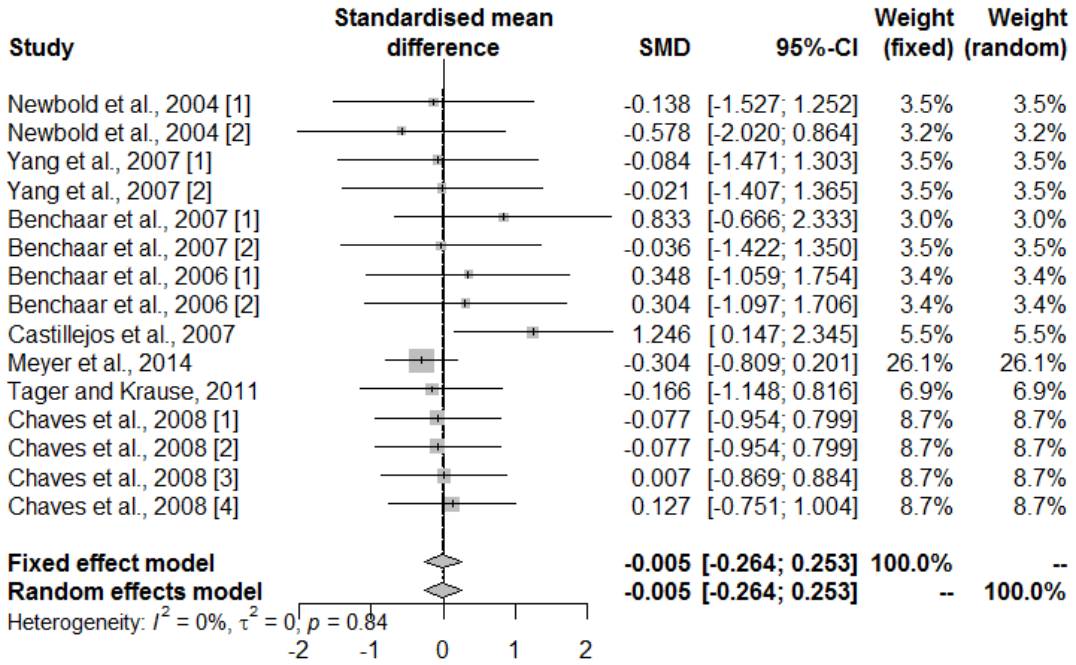


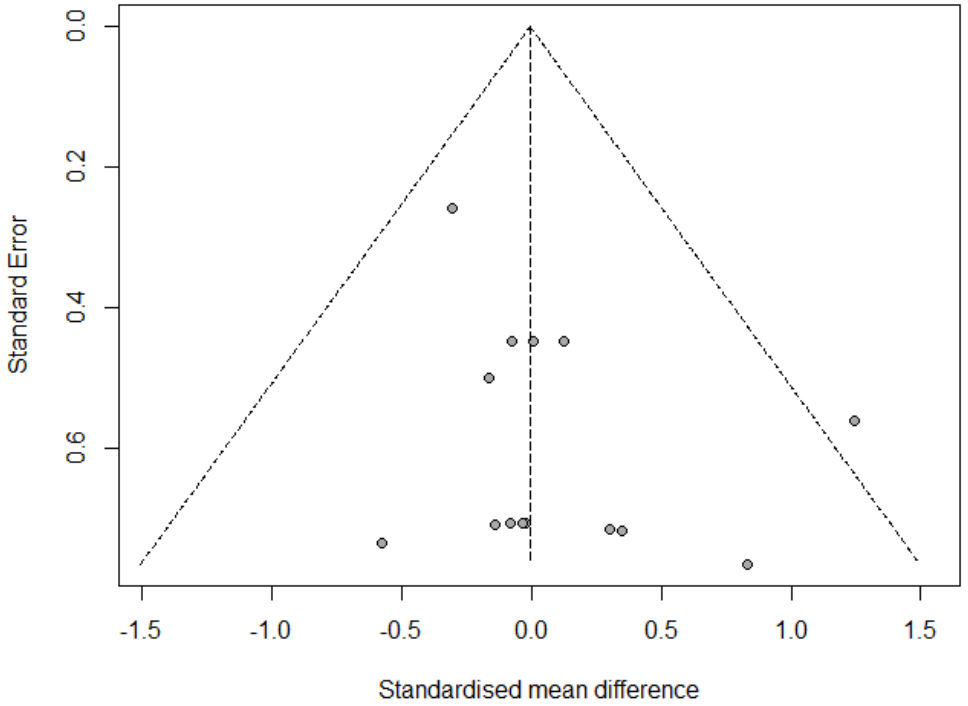
Results: yeast culture (A/P ratio)



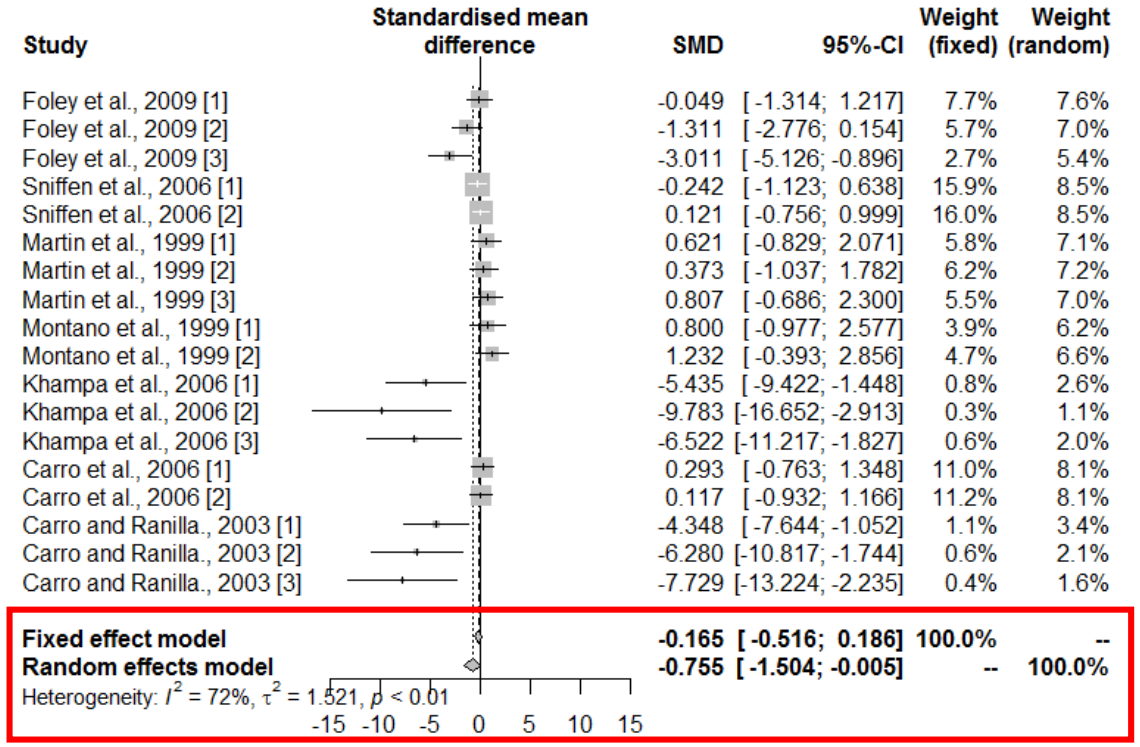


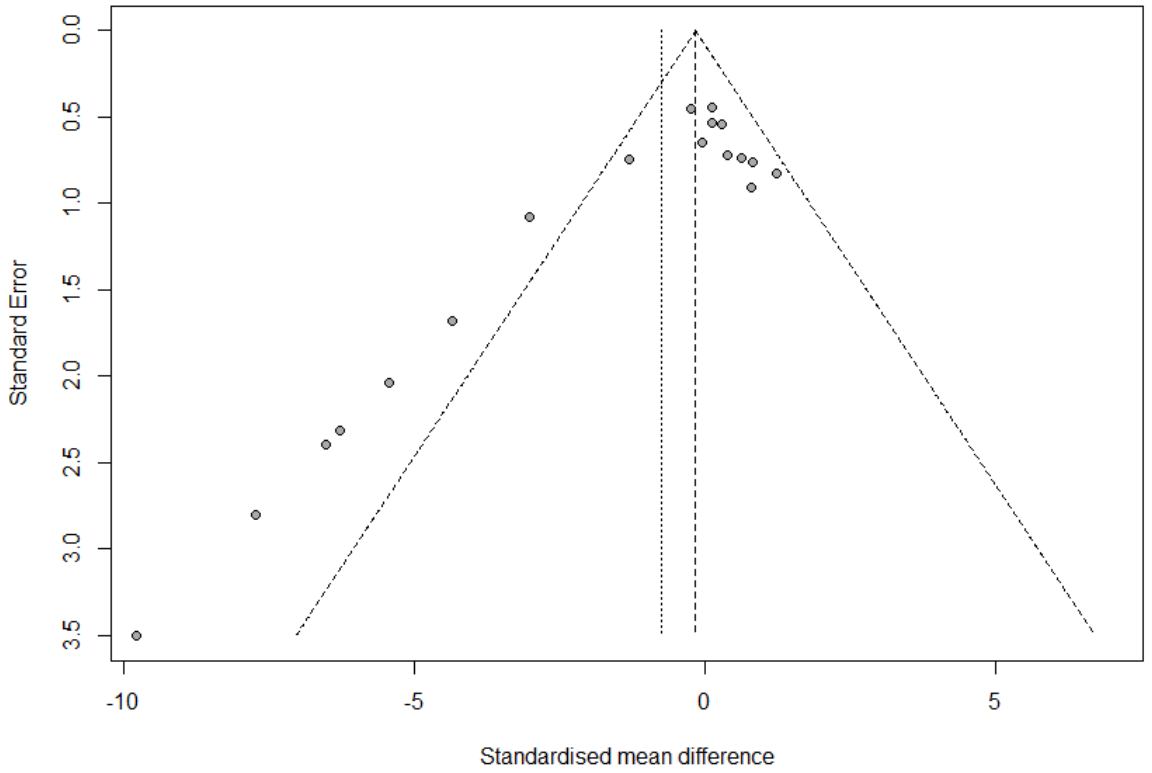
Results: essential oil (A/P ratio)





Results: malic acid (A/P ratio)

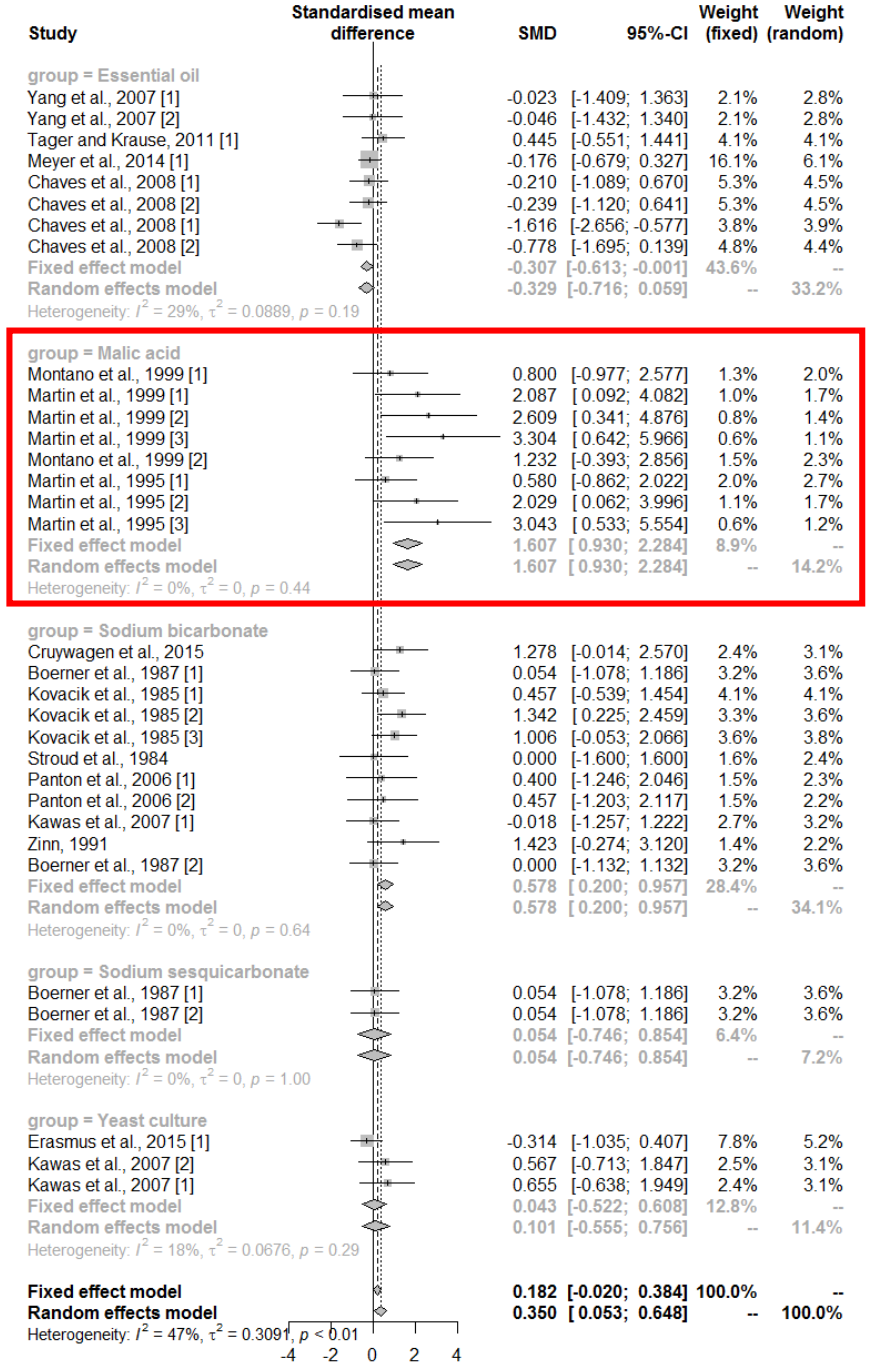




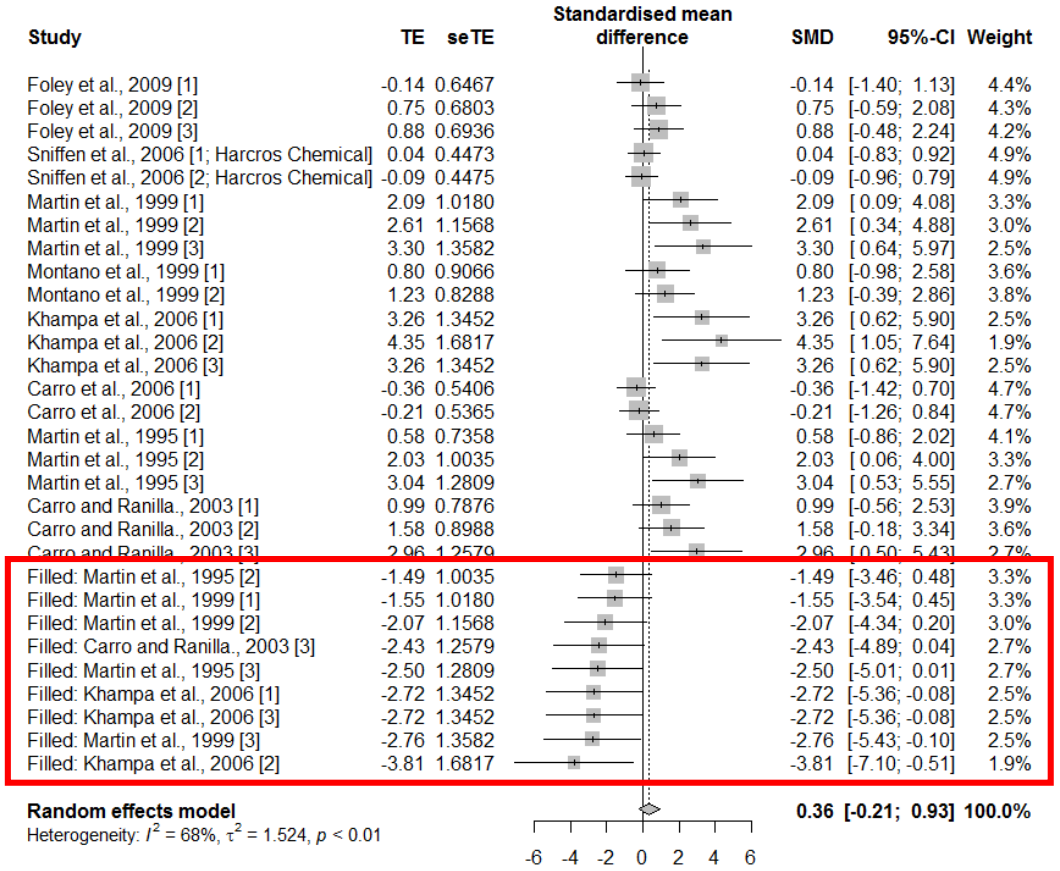
Results: Meta-ANOVA analysis result of feed additives on ruminal pH below 6.0 (SARA induced condition)

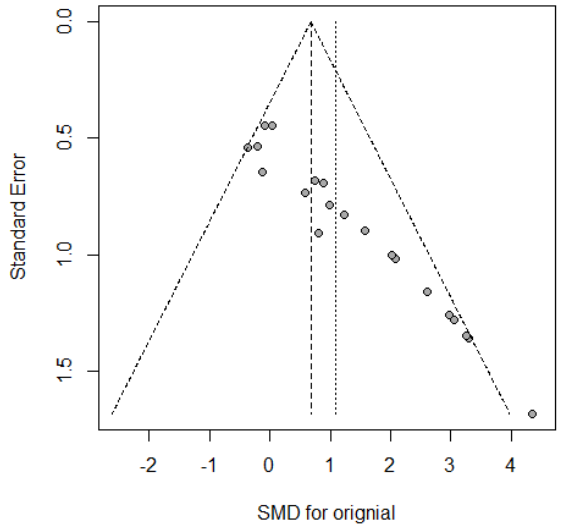
- 대조구의 pH가 6.0 이하인 연구(SARA 조건 유도)를 대상으로 Meta-ANOVA 분석을 수행함

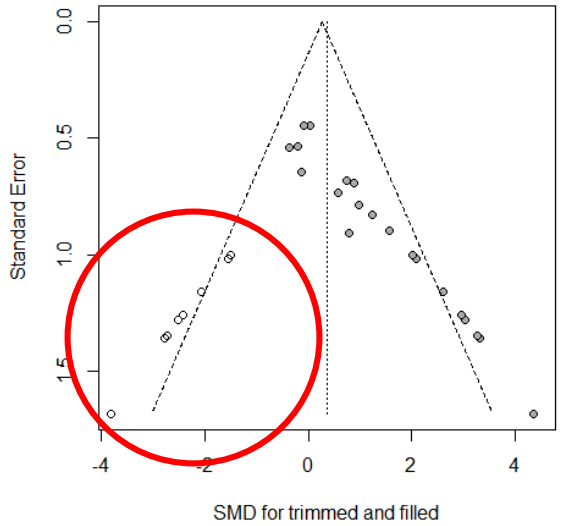
- **Malic acid의 SMD는 1.61로 매우 높은 효과크기를 보임**
- Sodium bicarbonate는 중간 효과크기를 보임
- Sodium sesquicarbonate 및 yeast culture는 작은 효과 크기를 보임
- Essential oil은 pH를 낮추는 경향을 보임(SMD = - 0.307)



Results: Trim-and-file analysis (pH; malic acid)





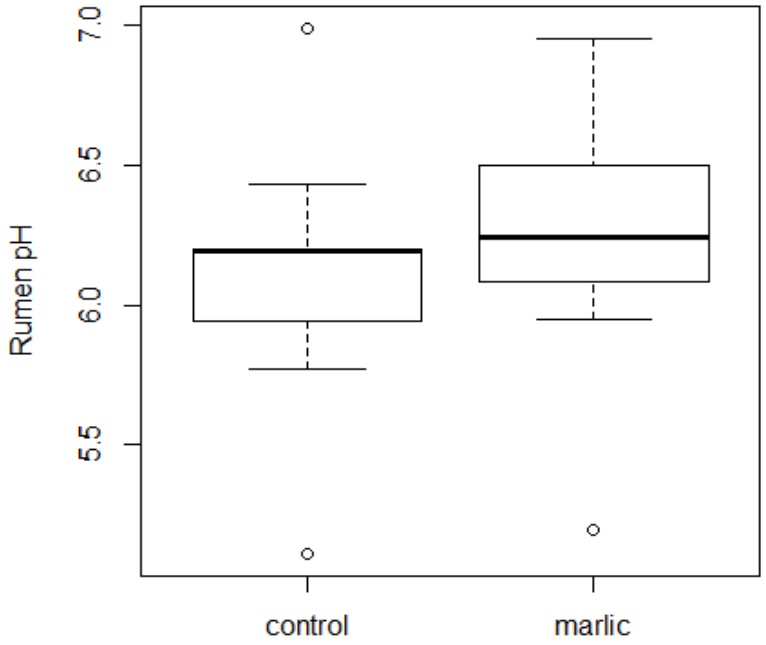


Duval, S., & Tweedie, R. 2000. A nonparametric “trim and fill” method of accounting for publication bias in meta-analysis. Journal of the American Statistical Association, 95(449), 89-98.

Results: Meta-regression analysis (pH; malic acid)

	Value	SE	DF	T value	P value
Intercept	6.125	0.152	32	40.2	<0.001
Treatment	0.140	0.045	32	3.1	0.004

AIC: 5.08; BIC: 15.21; Model, pH = intercept + treatment + random effect (study+animal+dose).



Mode of action: role of the malic acid in the prevention of ruminal pH changes (Castillo et al., 2004)

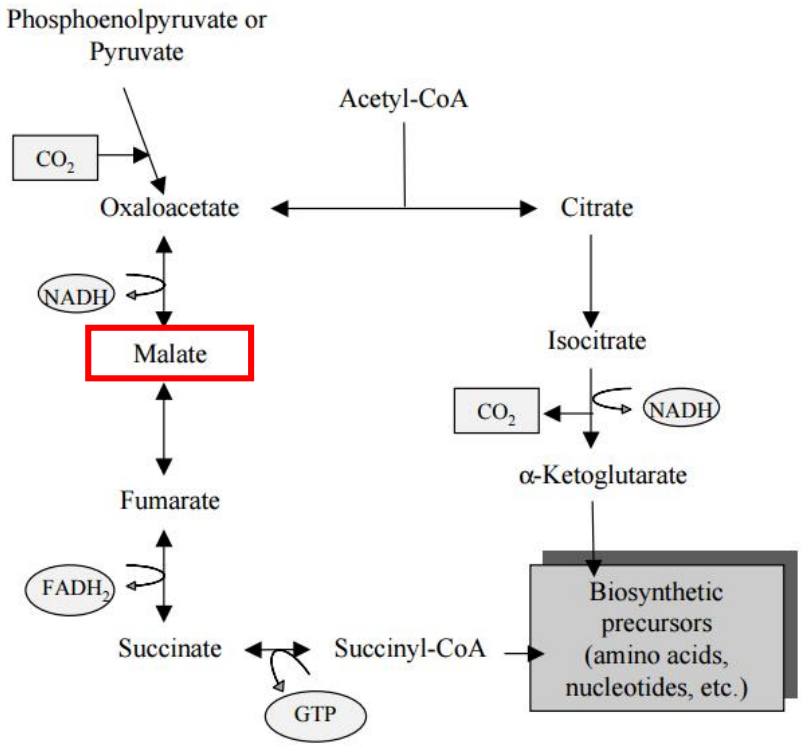


Fig. 1. Biosynthetic precursors produced by an incomplete citric acid cycle in anaerobic bacteria (adapted from Nelson and Cox, 2000).

C. Castillo et al. / Animal Feed Science and Technology 115 (2004) 101–116

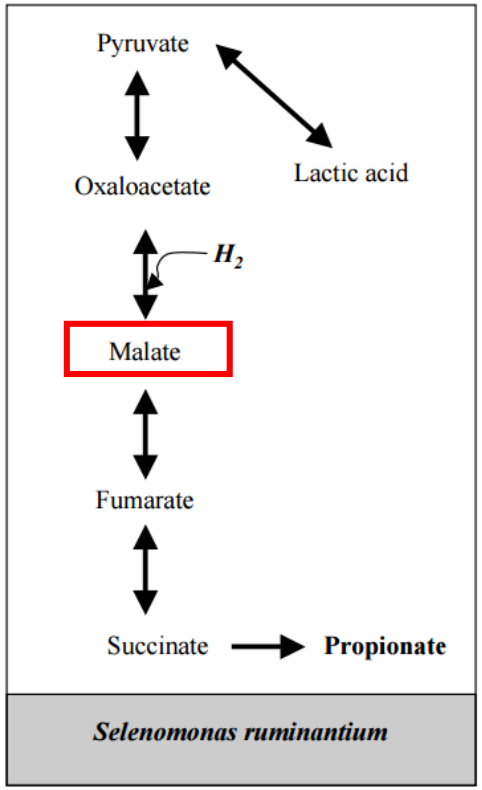


Fig. 2. Effect of malate in a medium that contains lactic acid (Crespo et al., 2002).

Castillo, C., J. L. Benedito, J. Méndez, V. Pereira, M. López-Alonso, M. Miranda, and J. Hernández. 2004. Organic Acids as a Substitute for Monensin in Diets for Beef Cattle. Animal Feed Science and Technology 115, no. 1–2: 101–16.

Conclusion

- 각종 사료첨가제가 반추위 발효에 미치는 영향에 대한 메타분석을 실시하였음
- Malic acid의 첨가급여 시 반추위 pH가 증가(SMD=1.08)하였으며, 특히 SARA induced condition에서 더 높은 효과크기를 보임(SMD=1.61)
- 이유, 분만, 전환기 등의 이유로 동물의 사료 섭취량과 에너지 공급량 등 급격한 변화가 있을 경우 SARA의 위험이 증가할 수 있음
- 이러한 경우, malic acid 와 sodium bicarbonate 등 각종 첨가제의 급여가 SARA의 발병을 예방 및 완화할 수 있을 것으로 보임

감사합니다

Thank you!

ありがとうございました

References (for Meta-analysis)

Arcos-García, J. L., F. A. Castrejón, G. D. Mendoza, and E. P. Pérez-Gavilán. “Effect of Two Commercial Yeast Cultures with Saccharomyces Cerevisiae on Ruminal Fermentation and Digestion in Sheep Fed Sugar Cane Tops.” Livestock Production Science 63, no. 2 (April 2000): 153–57. doi:10.1016/S0301-6226(99)00116-5.

Beauchemin, K. A., and S. M. McGinn. “Methane Emissions from Beef Cattle: Effects of Fumaric Acid, Essential Oil, and Canola Oil.” Journal of Animal Science 84, no. 6 (June 1, 2006): 1489–96. doi:10.2527/2006.8461489x.

Benchaar, C., H. V. Petit, R. Berthiaume, D. R. Ouellet, J. Chiquette, and P. Y. Chouinard. “Effects of Essential Oils on Digestion, Ruminal Fermentation, Rumen Microbial Populations, Milk Production, and Milk Composition in Dairy Cows Fed Alfalfa Silage or Corn Silage1.” Journal of Dairy Science 90, no. 2 (February 2007): 886–97. doi:10.3168/jds.S0022-0302(07)71572-2.

Benchaar, C., H. V. Petit, R. Berthiaume, T. D. Whyte, and P. Y. Chouinard. “Effects of Addition of Essential Oils and Monensin Premix on Digestion, Ruminal Fermentation, Milk Production, and Milk Composition in Dairy Cows1.” Journal of Dairy Science 89, no. 11 (November 2006): 4352–64. doi:10.3168/jds.S0022-0302(06)72482-1.

Boerner, B. J., F. M. Byers, G. T. Schelling, C. E. Coppock, and L. W. Greene. “Trona and Sodium Bicarbonate in Beef Cattle Diets: Effects on pH and Volatile Fatty Acid Concentrations.” Journal of Animal Science 65, no. 1 (July 1, 1987): 309–16. doi:10.2527/jas1987.651309x.

Carro, M. D., P. Lebzien, and K. Rohr. “Effects of Yeast Culture on Rumen Fermentation, Digestibility and Duodenal Flow in Dairy Cows Fed a Silage Based Diet.” Livestock Production Science 32, no. 3 (November 1, 1992): 219–29. doi:10.1016/S0301-6226(12)80003-0.

Carro, M. D., and M. J. Ranilla. “Effect of the Addition of Malate on in Vitro Rumen Fermentation of Cereal Grains.” British Journal of Nutrition 89, no. 02 (February 2003): 181. doi:10.1079/BJN2002759.

Carro, M. D., M. J. Ranilla, F. J. Giráldez, and A. R. Mantecón. “Effects of Malate on Diet Digestibility, Microbial Protein Synthesis, Plasma Metabolites, and Performance of Growing Lambs Fed a High-Concentrate Diet.” Journal of Animal Science 84, no. 2 (February 1, 2006): 405–10. doi:10.2527/2006.842405x.

Castillejos, L., S. Calsamiglia, A. Ferret, and R. Losa. “Effects of Dose and Adaptation Time of a Specific Blend of Essential Oil Compounds on Rumen Fermentation.” Animal Feed Science and Technology 132, no. 3–4 (January 15, 2007): 186–201. doi:10.1016/j.anifeedsci.2006.03.023.

Chaves, A. V., K. Stanford, L. L. Gibson, T. A. McAllister, and C. Benchaar. “Effects of Carvacrol and Cinnamaldehyde on Intake, Rumen Fermentation, Growth Performance, and Carcass Characteristics of Growing Lambs.” Animal Feed Science and Technology, Enzymes, Direct Fed Microbials and Plant Extracts in Ruminant Nutrition, 145, no. 1–4 (August 14, 2008): 396–408. doi:10.1016/j.anifeedsci.2007.04.016.

Clayton, E. H., I. J. Lean, J. B. Rowe, and J. W. Cox. “Effects of Feeding Virginiamycin and Sodium Bicarbonate to Grazing Lactating Dairy Cows.” Journal of Dairy Science 82, no. 7 (July 1, 1999): 1545–54. doi:10.3168/jds.S0022-0302(99)75382-8.

Cruywagen, C. W., S. Taylor, M. M. Beya, and T. Calitz. “The Effect of Buffering Dairy Cow Diets with Limestone, Calcareous Marine Algae, or Sodium Bicarbonate on Ruminal pH Profiles, Production Responses, and Rumen Fermentation.” Journal of Dairy Science 98, no. 8 (August 2015): 5506–14. doi:10.3168/jds.2014-8875.

Erasmus, L. J., P. H. Robinson, A. Ahmadi, R. Hinders, and J. E. Garrett. “Influence of Prepartum and Postpartum Supplementation of a Yeast Culture and Monensin, or Both, on Ruminal Fermentation and Performance of Multiparous Dairy Cows.” Animal Feed Science and Technology 122, no. 3–4 (September 1, 2005): 219–39. doi:10.1016/j.anifeedsci.2005.03.004.

Foley, P. A., D. A. Kenny, J. J. Callan, T. M. Boland, and F. P. O’Mara. “Effect of Dl-Malic Acid Supplementation on Feed Intake, Methane Emission, and Rumen Fermentation in Beef Cattle.” Journal of Animal Science 87, no. 3 (March 1, 2009): 1048–57. doi:10.2527/jas.2008-1026.

Haaland, G. L., and H. F. Tyrrell. “Effects of Limestone and Sodium Bicarbonate Buffers on Rumen Measurements and Rate of Passage in Cattle.” Journal of Animal Science 55, no. 4 (October 1, 1982): 935–42. doi:10.2527/jas1982.554935x.

Jacques, K. A., D. E. Axe, T. R. Harris, D. L. Harmon, K. K. Bolsen, and D. E. Johnson. “Effect of Sodium Bicarbonate and Sodium Bentonite on Digestion, Solid and Liquid Flow, and Ruminal Fermentation Characteristics of Forage Sorghum Silage-Based Diets Fed to Steers.” Journal of Animal Science 63, no. 3 (September 1, 1986): 923–32. doi:10.2527/jas1986.633923x.

Kawas, J. R., R. García-Castillo, H. Fimbres-Durazo, F. Garza-Cazares, J. F. G. Hernández-Vidal, E. Olivares-Sáenz, and C. D. Lu. “Effects of Sodium Bicarbonate and Yeast on Nutrient Intake, Digestibility, and Ruminal Fermentation of Light-Weight Lambs Fed Finishing Diets.” Small Ruminant Research 67, no. 2–3 (February 2007): 149–56. doi:10.1016/j.smallrumres.2005.09.010.

Kennelly, J. J., B. Robinson, and G. R. Khorasani. “Influence of Carbohydrate Source and Buffer on Rumen Fermentation Characteristics, Milk Yield, and Milk Composition in Early-Lactation Holstein Cows.” Journal of Dairy Science 82, no. 11 (November 1, 1999): 2486–96. doi:10.3168/jds.S0022-0302(99)75500-1.

Khampa, S., Metha Wanapat, C. Wachirapakorn, N. Nontaso, M. A. Wattiaux, and P. Rowlison. “Effect of Levels of Sodium DL-Malate Supplementation on Ruminal Fermentation Efficiency of Concentrates Containing High Levels of Cassava Chip in Dairy Steers.” ASIAN AUSTRALASIAN JOURNAL OF ANIMAL SCIENCES 19, no. 3 (2006): 368.

Koul, Vaneeta, Umesh Kumar, Vijay K Sareen, and Sudarshan Singh. “Mode of Action of Yeast Culture (YEA-SACC 1026) for Stimulation of Rumen Fermentation in Buffalo Calves.” Journal of the Science of Food and Agriculture 77, no. 3 (July 1, 1998): 407–13. doi:10.1002/(SICI)1097-0010(199807)77:3<407::AID-JSFA58>3.0.CO;2-J.

Kovacik, A. M., S. C. Loerch, and B. A. Dehority. “Effect of Supplemental Sodium Bicarbonate on Nutrient Digestibilities and Ruminal pH Measured Continuously.” Journal of Animal Science 62, no. 1 (January 1, 1986): 226–34. doi:10.2527/jas1986.621226x.

Kumar, U., V. K. Sareen, and S. Singh. “Effect of Saccharomyces Cerevisiae Yeast Culture Supplement on Ruminal Metabolism in Buffalo Calves given a High Concentrate Diet.” Animal Science 59, no. 2 (October 1994): 209–15. doi:10.1017/S0003356100007698.

Kung, L., E. M. Kreck, R. S. Tung, A. O. Hession, A. C. Sheperd, M. A. Cohen, H. E. Swain, and J. A. Z. Leedle. “Effects of a Live Yeast Culture and Enzymes on In Vitro Ruminal Fermentation and Milk Production of Dairy Cows1.” Journal of Dairy Science 80, no. 9 (September 1, 1997): 2045–51. doi:10.3168/jds.S0022-0302(97)76149-6.

Leventini, M. W., C. W. Hunt, R. E. Roffler, and D. G. Casebolt. “Effect of Dietary Level of Barley-Based Supplements and Ruminal Buffer on Digestion and Growth by Beef Cattle.” Journal of Animal Science 68, no. 12 (December 1990): 4334–44. doi:10.2527/1990.68124334x.

Martin, S. A., and M. N. Streeter. “Effect of Malate on in Vitro Mixed Ruminal Microorganism Fermentation.” Journal of Animal Science 73, no. 7 (July 1995): 2141–45. doi:10.2527/1995.7372141x.

Martin, S. A., M. N. Streeter, D. J. Nisbet, G. M. Hill, and S. E. Williams. “Effects of DL-Malate on Ruminal Metabolism and Performance of Cattle Fed a High-Concentrate Diet.” Journal of Animal Science 77, no. 4 (April 1999): 1008–15. doi:10.2527/1999.7741008x.

Meyer, N. F., G. E. Erickson, T. J. Klopfenstein, M. A. Greenquist, M. K. Luebbe, P. Williams, and M. A. Engstrom. “Effect of Essential Oils, Tylosin, and Monensin on Finishing Steer Performance, Carcass Characteristics, Liver Abscesses, Ruminal Fermentation, and Digestibility.” Journal of Animal Science 87, no. 7 (July 1, 2009): 2346–54. doi:10.2527/jas.2008-1493.

Montaño, M. F., W. Chai, T. E. Zinn-Ware, and R. A. Zinn. “Influence of Malic Acid Supplementation on Ruminal pH, Lactic Acid Utilization, and Digestive Function in Steers Fed High-Concentrate Finishing Diets.” Journal of Animal Science 77, no. 3 (March 1999): 780–84. doi:10.2527/1999.773780x.

Newbold, C. J, F. M McIntosh, P Williams, Riccardo Losa, and R. J Wallace. “Effects of a Specific Blend of Essential Oil Compounds on Rumen Fermentation.” Animal Feed Science and Technology 114, no. 1–4 (May 3, 2004): 105–12. doi:10.1016/j.anifeedsci.2003.12.006.

Paton, Laura J, Karen A Beauchemin, Douglas M Veira, and Marina A. G. von Keyserlingk. “Use of Sodium Bicarbonate, Offered Free Choice or Blended into the Ration, to Reduce the Risk of Ruminal Acidosis in Cattle.” Canadian Journal of Animal Science 86, no. 3 (September 2006): 429–37. doi:10.4141/A06-014.

Putnam, D. E., C. G. Schwab, M. T. Socha, N. L. Whitehouse, N. A. Kierstead, and B. D. Garthwaite. “Effect of Yeast Culture in the Diets of Early Lactation Dairy Cows on Ruminal Fermentation and Passage of Nitrogen Fractions and Amino Acids to the Small Intestine1,2.” Journal of Dairy Science 80, no. 2 (February 1, 1997): 374–84. doi:10.3168/jds.S0022-0302(97)75947-2.

Reynolds, W. K., C. W. Hunt, T. Moen, and J. A. Loesche. “Comparison of Corn and Barley with and without Ruminal Buffer in Supplements Fed in Wheat Straw-Based Diets to Beef Steers.” Journal of Animal Science 71, no. 5 (May 1993): 1326–34. doi:10.2527/1993.7151326x.

Russell, J. R., A. W. Young, and N. A. Jorgensen. “Effect of Sodium Bicarbonate and Limestone Additions to High Grain Diets on Feedlot Performance and Ruminal and Fecal Parameters in Finishing Steers.” Journal of Animal Science 51, no. 4 (October 1, 1980): 996–1002. doi:10.2527/jas1980.514996x.

Santra, A, O. H Chaturvedi, M. K Tripathi, R Kumar, and S. A Karim. “Effect of Dietary Sodium Bicarbonate Supplementation on Fermentation Characteristics and Ciliate Protozoal Population in Rumen of Lambs.” Small Ruminant Research 47, no. 3 (March 2003): 203–12. doi:10.1016/S0921-4488(02)00241-9.

Sniffen, C. J., C. S. Ballard, M. P. Carter, K. W. Cotanch, H. M. Dann, R. J. Grant, P. Mandebvu, M. Suekawa, and S. A. Martin. “Effects of Malic Acid on Microbial Efficiency and Metabolism in Continuous Culture of Rumen Contents and on Performance of Mid-Lactation Dairy Cows.” Animal Feed Science and Technology 127, no. 1–2 (March 30, 2006): 13–31. doi:10.1016/j.anifeedsci.2005.07.006.

Stroud, T. E., J. E. Williams, D. R. Ledoux, and J. A. Paterson. “The Influence of Sodium Bicarbonate and Dehydrated Alfalfa as Buffers on Steer Performance and Ruminal Characteristics.” Journal of Animal Science 60, no. 2 (February 1, 1985): 551–59. doi:10.2527/jas1985.602551x.

Tager, L. R., and K. M. Krause. “Effects of Essential Oils on Rumen Fermentation, Milk Production, and Feeding Behavior in Lactating Dairy Cows.” Journal of Dairy Science 94, no. 5 (May 2011): 2455–64. doi:10.3168/jds.2010-3505.

Thrune, M., A. Bach, M. Ruiz-Moreno, M. D. Stern, and J. G. Linn. “Effects of Saccharomyces Cerevisiae on Ruminal pH and Microbial Fermentation in Dairy Cows: Yeast Supplementation on Rumen Fermentation.” Livestock Science 124, no. 1–3 (September 2009): 261–65. doi:10.1016/j.livsci.2009.02.007.

Tripathi, M. K, A Santra, O. H Chaturvedi, and S. A Karim. “Effect of Sodium Bicarbonate Supplementation on Ruminal Fluid pH, Feed Intake, Nutrient Utilization and Growth of Lambs Fed High Concentrate Diets.” Animal Feed Science and Technology 111, no. 1–4 (January 12, 2004): 27–39. doi:10.1016/j.anifeedsci.2003.07.004.

Yang, W. Z., C. Benchaar, B. N. Ametaj, A. V. Chaves, M. L. He, and T. A. McAllister. “Effects of Garlic and Juniper Berry Essential Oils on Ruminal Fermentation and on the Site and Extent of Digestion in Lactating Cows1.” Journal of Dairy Science 90, no. 12 (December 2007): 5671–81. doi:10.3168/jds.2007-0369.

Zinn, R. A. “Comparative Feeding Value of Steam-Flaked Corn and Sorghum in Finishing Diets Supplemented with or without Sodium Bicarbonate.” Journal of Animal Science 69, no. 3 (March 1991): 905–16. doi:10.2527/1991.693905x.