Black Sea Journal of Agriculture
doi: 10.47115/bsagriculture.1373857

Open Access Journal
e-ISSN: 2618 – 6578

Research Article
Volume 6 - Issue 6: 710-717 / November 2023

COMPARISON OF TEN DIFFERENT MATHEMATICAL MODELS USED IN IN-VITRO GAS PRODUCTION TECHNIQUE

Mustafa ŞAHİN[1]*

[1]*Kahramanmaraş Sütçü İmam University, Faculty of Agriculture, Dep. of Agricultural Biotechnology, 46100, Kahramanmaraş, Türkiye*

Abstract: In this study, the usability of models commonly used in in vitro gas production techniques in different feed sources was comparatively investigated. For this purpose, Richard, Logistic, Orskov, Verhulst, Janoschek, Weibull, Bridges, Mitscherling, Monomolecular and Von Bertalanffy models, which are widely used in the literature, were used. In comparing these models, criteria such as mean square error (MSE), coefficient of determination(R^2), corrected coefficient of determination ($\bar{R}^2$), accuracy factor (AF), bias factor (BF), Akaike information criterion (AIC) and Bayesian information criterion (BIC) were used. As a result of the research, according to these criteria, the best model in Arbutus andrachne plant was determined as Richard, and the worst model was determined as Janoscheck and Weibull model. For Arbutus unedo, *Ceratonia siliqua* and *Laurus nobilis* L. plants, the best models were determined as Orskov, Mitscherling, Monomolecular and Von Bertalanffy models, and the worst models were Logistic and Verhulst models.

Keywords: In-vitro, Ruminant, Model comparison

***Corresponding author:** 1Kahramanmaraş Sütçü İmam University, Faculty of Agriculture, Dep. of Agricultural Biotechnology, 46100, Kahramanmaraş, Türkiye
E mail: ms66@ksu.edu.tr (M. ŞAHİN)
Mustafa ŞAHİN https://orcid.org/0000-0003-3622-4543

Received: October 10, 2023
Accepted: October 31, 2023
Published: November 01, 2023
Cite as: Şahin M. 2023. Comparison of ten different mathematical models used in in-vitro gas production technique. BSJ Agri, 6(6): 710-717.

1. Introduction

Different methods such as in-vivo, in-vitro and in-situ are used to determine the feed value of feeds used in ruminant animal feeding. Although the most reliable results are obtained from in-vivo studies, they are not preferred because they are difficult to study, costly and require large amounts of feed. For these reasons, the in-vitro method based on the measurement of fermentation residues (gas) is preferred. In this method, gas measurements are made at certain intervals after the start of fermentation (3, 6, 12, 24, 48, 72, 96 and 120 hours). The relationship between rumen fermentation and gas production has been known for a long time. It has been reported that the applications of fermentative gas measurement technique in the rumen date back to 1939 and that this technique is the measurement of microbial activity (Getachew et al., 1998, Canbolat et al., 2005).

By using the amount of gas produced, the performance of animals, feed consumption, microbial protein digestion, digestibility levels of feeds, metabolic energy and net energy values of feeds, determination of protein and dry matter degradability in the rumen, in vitro degradation rate and amount of feeds can be determined. Due to advances in computers and software, many new equations have been developed in modeling gas production curves. It is extremely important to choose the most statistically accurate and meaningful model or models in terms of animal nutrition among these equations. Values of gas measurements show a sigmoidal distribution and it is extremely difficult to model this distribution with linear models. For this reason, it became necessary to use non-linear models, which are more complex than linear models. After the models are created, it is extremely important to compare the models statistically and choose the most appropriate model. In comparing models, criteria such as error mean squares, coefficient of determination, corrected coefficient of determination, accuracy factor, deviation factor, Akaike information criterion and Bayesian information criterion are used.

In this study, 10 different models used in the literature were applied on the gas production values of 4 different feed sources. At the same time, it is aimed to create an important reference source in the relevant field by obtaining model comparison criteria used in the literature.

2. Materials and Methods

2.1. Materials

In this study, gas production values obtained from *Arbutus andrachne*, *Arbutus unedo*, *Ceratonia siliqua* and *Laurus nobilis* L. plants were used. Gas values of these plants were obtained in the laboratories of KSÜ, feed and animal nutrition department. For this purpose, the amounts of gas produced from these four different feed samples were measured at different time periods (at 3, 6, 12, 24, 48, 72 and 96 hours) using the in-vitro gas production technique.

2.2. Methods

2.2.1. Equations used in modeling

In modeling the gas values produced from four different feed sources, Richard, logistic, Orskov, Verhulst, Janoschek, Weibull, Bridges, Mitscherling, Monomolecular and Von Bertalanffy models, which are widely used in the literature, were used (Brody, 1945; Richards, 1959; Schofield et al., 1994; Groot et al., 1996; Orskov and Mcdonald, 1979). SAS statistical package program was used to estimate the parameters of the models and obtain the estimated gas production curves (SAS, 1999). The models used and their explanations are given in Table 1, and the in vitro gas production parameters of the models are given in Table 2 (Lopez et al., 1999; Kamalak et al., 2004; Canbolat et al., 2007; Üçkardeş and Efe, 2014).

Table 1. Mathematical models used in in-vitro gas production technique

Models	Equations
Richard	$Y = a(1+be(-ct))^{d}$
Logistic	$Y = a / (1 + e^{b-ct})$
Orskov	$Y = a + b\ (1 - e^{ct})$
Verhulst	$Y = a / (1 - be^{ct})$
Janoscheck	$Y = a - (a - b)e^{-ct^{d}}$
Weibull	$Y = a - be^{-ct^{d}}$
Bridges	$Y = a + b\ (1 - e^{-(ct^{d})})$
Mitscherling	$Y = a(1 - be^{-ct})$
Monomolecular	$Y = a - be^{-ct}$
Von Bertalanffy	$Y = a - (a - b)e^{-ct}$

Table 2. The models used in the study and parameter expressions

Models	A	B	C	TG	SP
Richard	$a(1+b)^{d}$	$a- a(1+b)^{d}$	c	a	d , b
Logistics	a/(1+e(b))	a-a/(1+e(b))	c	a	b
Orskov	a	b	c	a+b	-
Verhulst	a/(1-b)	a- a/(1-b)	c	a	b
Janoscheck	b	a-b	c	a	d
Weibull	a-b	b	c	a	d
Bridges	a	b	c	a+b	d
Mitscherling	a(1-b)	a- a(1-b)	c	a	-
Monomolecular	a-b	b	c	a	-
Von Bertalanffy	b	a-b	c	a	-

A= amount of gas produced from easily fragmented part, B= amount of gas produced from the slowly degraded part, C= gas production rate, TG= total gas, SP= shape parameter.

2.2.2. Model Comparison Criteria

In modeling studies, it is not enough to obtain models with the appropriate equations for the existing data set (Özkan and Sahin, 2006; Sahin et al., 2011; Bayazıt et al., 2022). It is also necessary to evaluate how statistically sufficient the created models are in describing the data set. For this purpose, in the studies of modeling gas production curves, as in all disciplines, in the statistical comparison of the models obtained, the mean squares of error, coefficient of determination, corrected coefficient of determination, accuracy factor, bias factor, Durbin-Watson autocorrelation value, Akaike information criterion and Bayesian information criterion is used (Korkmaz et al., 2011; Cankaya et al., 2014; Tahtalı et al., 2020; Gök et al., 2021). Equations of these comparison criteria are given in Table 3.

Table 3. Model comparison criteria

Criterion	Equality
Error Mean Squares	EMS = ESS/EDF
Coefficient of Determination	$R^2 = 1 - (ESS/TSS)$
Adjusted Coefficient of Determination	$\bar{R}^2 = 1 - (1 - R^2)(n - 1/(n - p - 1))$
Accuracy Factor	$AF = 10^{\sum_{i=1}^{n}\lvert\log(\hat{Y}_i/Y_i)\rvert/n}$
Bias Factor	$BF = 10^{\sum_{i=1}^{n}\log(\hat{Y}_i/Y_i)/n}$
Durbin-Watson Value	$DW = \frac{\sum_{i=2}^{n}(e_1 - e_2)^2}{\sum_{i=1}^{n} e_1^2}$
Akaike Knowledge Criteria	$AIC = nxln\left(\frac{ESS}{n}\right) + 2k$
Bayesian Information Criterion	$BIC = nxln\left(\frac{ESS}{n}\right) + kln(n)$

ESS= error sum of squares, EDF= error degrees of freedom, TSS= total sum of squares, n= sample size, p= Number of independent variable, $\hat{Y}_i$= estimated value, Y_i= observation value, e_i= the term residual, k= Number of parameters.

3. Results and Discussion

3. Results and Discussion

Parameter estimates for ten different models for four different feed sources are given in Table 4, Table 5, Table 6 and Table 7. Additionally, for four different feed sources, in Table 8, Table 9, Table 10 and Table 11, mean square error, coefficient of determination, corrected coefficient of determination, bias and accuracy factors, Durbin Watson, Akaike information criterion and Bayesian information criterion values of 10 different models are given.

Table 4. Parameter Estimates for *Arbutus andrachne*

Models	Parameters			
	a	b	c	d
Richard	56,87	-0,006	0,002	0,17
Logistic	41,91	0,23	0,09	-
Orskov	16,8	25,69	0,05	-
Verhulst	41,91	-1,26	-0,09	-
Janoscheck	295,6	-754,7	1,33	0,01
Weibull	152,5	665,6	1,58	0,02
Bridges	-535,1	619,2	-2,17	0,04
Mitscherling	42,49	0,6	0,05	-
Monomolecular	42,49	25,69	0,05	-
Von Bertalanffy	42,49	16,8	0,05	-

Table 5. Parameter Estimates for *Arbutus unedo*

Models	Parameters			
	a	b	c	d
Richard	41,3	0,05	0,04	0,4
Logistic	41,25	0,23	0,08	-
Orskov	16,29	25,34	0,06	-
Verhulst	41,25	-1,26	-0,08	-
Janoscheck	42,34	12,25	0,13	0,76
Weibull	42,34	30,08	0,13	0,76
Bridges	12,258	30,08	-0,13	0,76
Mitscherling	41,64	0,6	0,06	-
Monomolecular	41,64	25,34	0,06	-
Von Bertalanffy	41,64	16,29	0,06	-

Table 6. Parameter Estimates for *Ceratonia siliqua*

Models	Parameters			
	a	b	c	d
Richard	32,14	0,32	0,7	0,98
Logistic	41,95	0,67	0,124	-
Orskov	10,48	31,83	0,07	-
Verhulst	41,95	-1,96	-0,12	-
Janoscheck	42,33	10,44	0,07	0,99
Weibull	42,33	31,88	0,07	0,99
Bridges	10,44	31,88	-0,07	0,99
Mitscherling	42,33	0,75	0,07	-
Monomolecular	42,32	31,83	0,07	-
Von Bertalanffy	42,32	10,48	0,07	-

Table 7. Parameter Estimates for *Laurus nobilis* L.

Models	Parameters			
	a	b	c	d
Richard	144,4	-0,0001	0,0001	0,25
Logistic	43,01	0,47	0,05	-
Orskov	14,47	30,21	0,03	-
Verhulst	43,01	-1,6	-0,05	-
Janoscheck	176,5	-19,8	0,15	0,19
Weibull	147	161	0,169	0,2
Bridges	-26,67	168,8	-0,24	0,16
Mitscherling	44,69	0,67	0,031	-
Monomolecular	44,69	30,21	0,031	-
Von Bertalanffy	44,69	14,47	0,031	-

When Table 4 and Table 7 are examined, it is seen that the "a" parameter values are equal in the Logistic and Verhulst models in the *Arbutus andrachne* and *Laurus nobilis* L. plants. A similar situation is also valid in the Mitscherling, Monomolecular and Von Bertalanffy models. When Table 5 and Table 6 are examined, the "a" parameter was found to be equal in Logistic and Verhulst, Janoscheck and Weibull, Mitscherling, Monomolecular and Von Bertalanffy models for *Arbutus unedo* and *Ceratonia siliqua* plants. In the Verhulst model, "b" and "c" parameters were obtained as negative in all feed sources. The same applies to the “c” parameter of the Bridges model.

When Table 8 is examined, it can be seen that for the *Arbutus andrachne* plant, all model comparison criteria of the Orskov, Mitscherling, Monomolecular and Von Bertalanffy models are equal, except for the bias factor. A similar situation is valid for logistic and Verhulst models. Considering the goodness of fit criteria, the best model in *Arbutus andrachne* is the Richard model. It can be said that Orskov, Mitscherling, Monomolecular and Von Bertalanffy models are in second place. The worst results were obtained from Janoscheck and Weibull models. The positions of the curves according to the point distribution given in Figure 1 support the results obtained. When the values in Table 9 for the *Arbutus unedo* plant are examined, it is seen that the best models are the Orskov, Mitscherling, Monomolecular and Von Bertalanffy models. Considering the mean squares of error, Akaike information criterion and Bayesian information criterion, the worst results were obtained in the Logistic and Verhulst models. It can be said that there is a negative autocorrelation problem in the Rizhard, Janoscheck, Weibull and Bridges models (Durbin-Watson negative autocorrelation limit value = 3.525). High coefficient of determination values were obtained in all models. The positions of the obtained curves according to the point distribution given in Figure 2 support this situation.

Table 8. Comparison criteria for *Arbutus andrachne*

Models	EMS	R^2	$\bar{R}^2$	AF	BF	DW	AIC	BIC
Richard	3,10	0,999	0,999	1,023	1,002	2,676	34,209	101,389
Logistic	5,98	0,997	0,997	1,048	1,002	2,206	73,440	122,129
Orskov	4,69	0,961	0,954	1,039	1,002	2,361	58,898	108,103
Verhulst	5,98	0,997	0,997	1,048	1,003	2,206	73,440	122,129
Janoscheck	20,6	0,872	0,847	1,085	1,003	0,950	182,587	244,502
Weibull	8,38	0,948	0,938	1,053	1,002	1,489	78,917	144,510
Bridges	4,59	0,972	0,966	1,037	1,008	2,194	46,863	113,594
Mitscherling	4,69	0,961	0,954	1,039	1,015	2,361	58,898	108,103
Monomolecular	4,69	0,961	0,954	1,039	1,004	2,361	58,898	108,103
Von Bertalanffy	4,69	0,961	0,954	1,039	1,001	2,361	58,898	108,103

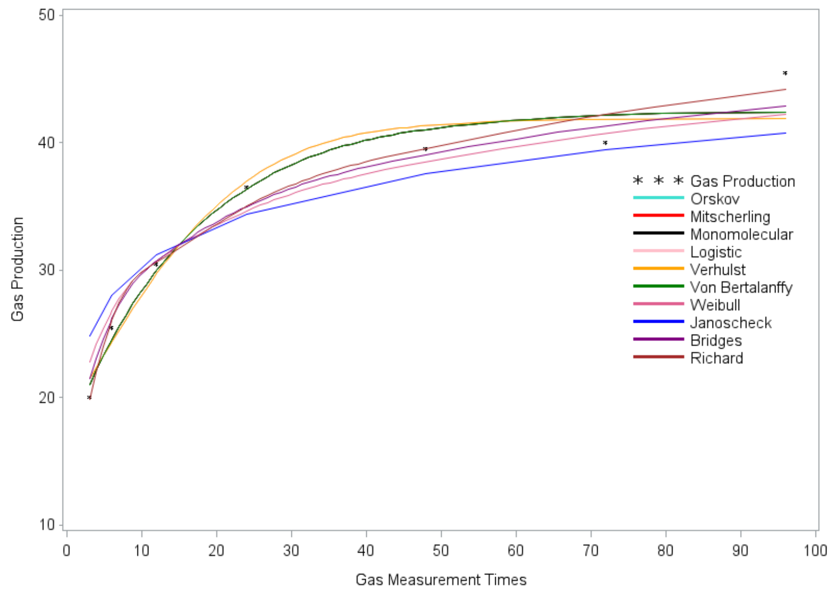

Figure 1. Curves were obtained from 10 different models for gas production values of *Arbutus andrachne*.

Table 9. Comparison criteria for *Arbutus unedo*

Models	EMS	R^2	$\bar{R}^2$	AF	BF	DW	AIC	BIC
Richard	0,26	0,999	0,999	1,008	1,000	3,52	10,204	78,23
Logistic	1,02	0,999	0,999	1,024	1,001	2,11	23051,2	22284,6
Orskov	0,39	0,997	0,996	1,013	1,000	2,64	1287,9	1293,5
Verhulst	1,02	0,999	0,999	1,024	1,001	2,11	23051,2	22284,6
Janoscheck	0,27	0,998	0,998	1,008	1,000	3,45	1289,9	1312,6
Weibull	0,27	0,998	0,998	1,008	1,000	3,45	1289,9	1312,6
Bridges	0,27	0,998	0,998	1,008	1,000	3,45	1546,4	1559,9
Mitscherling	0,39	0,997	0,996	1,013	1,000	2,64	1287,9	1293,5
Monomolecular	0,39	0,997	0,996	1,013	1,000	2,64	1287,9	1293,5
Von Bertalanffy	0,39	0,997	0,996	1,013	1,000	2,64	1287,9	1293,5

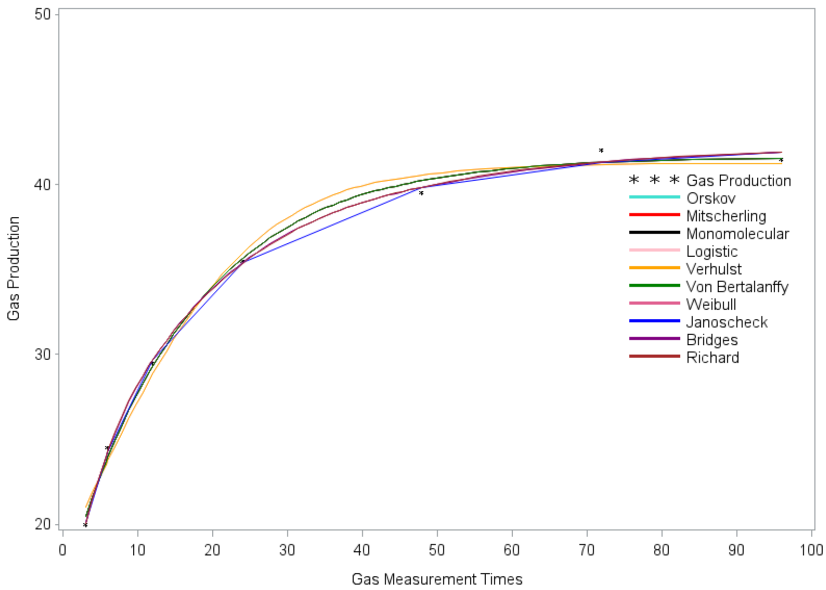

Figure 2. Curves were obtained from 10 different models for gas production values of *Arbutus unedo*.

When the values given in Table 10 are examined for the *Laurus nobilis* plant, it can be said that the best results belong to the Orskov, Monomolecular and Richard models. Logistic and Verhulst models have the worst results due to the very high Akaike information criterion and Bayesian information criterion values, and the Janoscheck model has the worst results due to the very high mean squares of error value. It can be said that there is a positive autocorrelation problem in the Mitscherling and Von Bertalanffy models (Durbin-Watson positive autocorrelation limit value = 0.475). The positions of the curves according to the point distribution given in Figure 3 support the results obtained. When the results in Table 11 for the *Ceratonia siliqua* plant are examined, it is seen that the best results are obtained from the Orskov, Mitscherling, Monomolecular and Von Bertalanffy models. It can be said that the Logistic and Verhulst models have the worst results due to their high mean squares of error, Akaike information criterion and Bayesian information criterion values. The positions of the curves according to the point distribution given in Figure 4 support the results obtained.

As a result, in terms of model fit criteria, it was concluded that the best model for Arbutus andrachne was the Richard model, and the worst models were the Janoscheck and Weibull model. In Arbutus unedo, Ceratonia siliqua and Laurus nobilis L. plants, the best models were determined as Orskov, Mitscherling, Monomolecular and Von Bertalanffy models, and the worst models were Logistic and Verhulst models. These results are parallel to the results obtained by Üçkardeş and Efe (2014).

Gas production curves were obtained after making coefficient estimates of Richard, Logistic, Orskov, Verhulst, Janoschek, Weibull, Bridges, Mitscherling, Monomolecular and Von Bertalanffy models for four different feed sources are shown in Figure 1, Figure 2, Figure 3 and Figure 4.

Table 10. Comparison criteria for *Laurus nobilis* L.

Models	EMS	R^2	$\bar{R}^2$	AF	BF	DW	AIC	BIC
Richard	14,4	0,994	0,993	1,042	1,003	1,96	130,1	193,8
Logistic	6,08	0,997	0,996	1,042	1,003	1,96	20297,9	19628,9
Orskov	3,25	0,981	0,977	1,042	1,003	1,96	1946,3	1928,6
Verhulst	6,08	0,997	0,996	1,063	1,007	1,85	20297,9	19628,9
Janoscheck	11,5	0,950	0,940	1,063	1,007	1,85	1948,3	1947,6
Weibull	4,96	0,978	0,974	1,042	1,003	1,96	1948,3	1947,6
Bridges	4,69	0,980	0,975	1,034	0,980	1,23	1948,3	1947,6
Mitscherling	3,25	0,981	0,977	1,077	0,928	0,59	1946,3	1928,6
Monomolecular	3,25	0,981	0,977	1,032	0,984	1,36	1946,3	1928,6
Von Bertalanffy	3,25	0,981	0,977	1,081	0,925	0,57	1946,3	1928,6

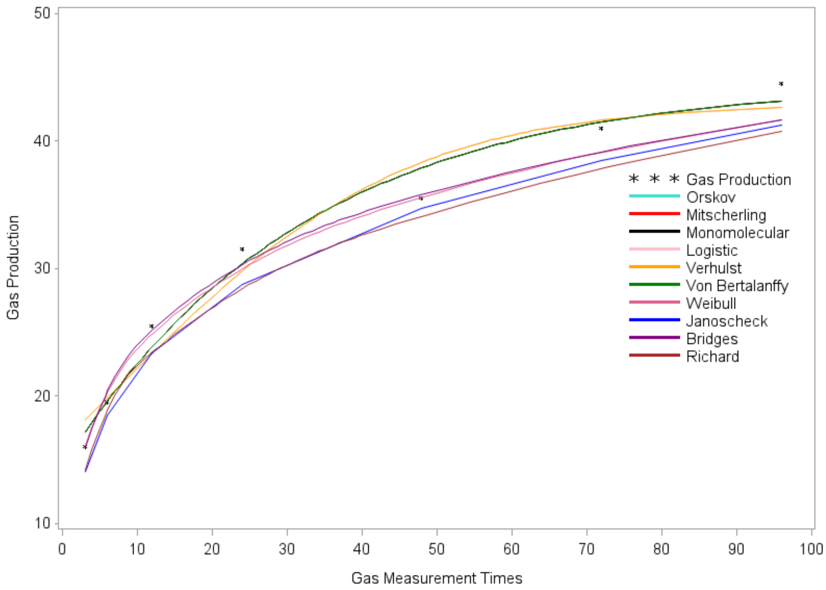

Figure 3. Curves were obtained from 10 different models for gas production values of *Laurus nobilis* L.

Table 11. Comparison criteria for *Ceratonia siliqua*

Models	EMS	R^2	$\bar{R}^2$	AF	BF	DW	AIC	BIC
Richard	0,06	0,999	0,999	1,005	1,000	3,29	8,57	76,6
Logistic	0,56	0,999	0,999	1,019	1,002	2,06	23578,2	22792,9
Orskov	0,05	0,999	0,999	1,005	1,000	3,28	1815,0	1801,89
Verhulst	0,56	0,999	0,999	1,019	1,002	2,06	23578,2	22792,9
Janoscheck	0,06	0,999	0,999	1,005	1,000	3,29	1817,0	1820,92
Weibull	0,06	0,999	0,999	1,005	1,000	3,29	1817,0	1820,92
Bridges	0,06	0,999	0,999	1,005	1,000	3,29	1817,0	1820,92
Mitscherling	0,05	0,999	0,999	1,005	1,000	3,28	1815,0	1801,89
Monomolecular	0,05	0,999	0,999	1,005	1,000	3,28	1815,0	1801,89
Von Bertalanffy	0,05	0,999	0,999	1,005	1,000	3,28	1815,0	1801,89

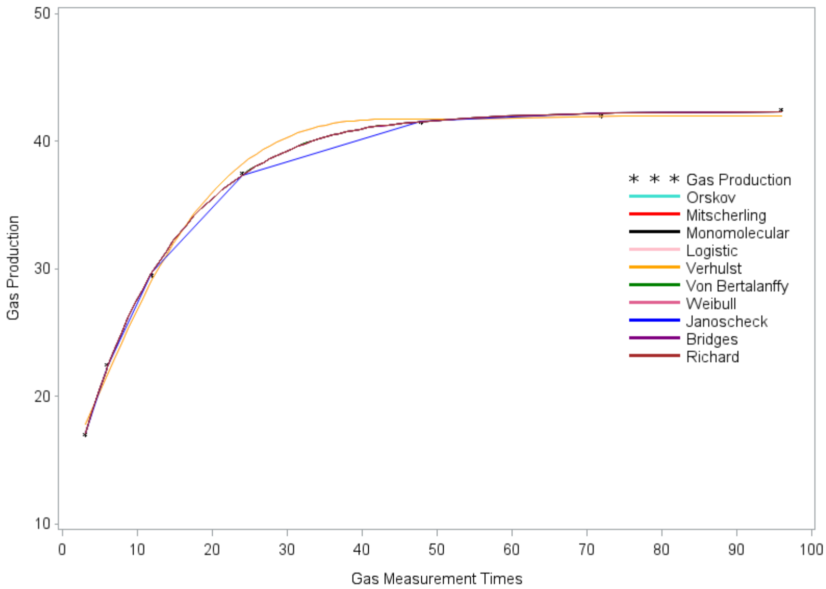

Figure 4. Curves were obtained from 10 different models for gas production values of *Ceratonia siliqua*.

As can be seen here, although gas production curves show a certain sigmoidal distribution, they may differ slightly in different feed sources and studies. For this reason, it is extremely important to include as many equations as possible in modeling studies to obtain reliable curves and parameters. On the other hand, it is of particular importance that parameters such as the amount of gas produced from the easily degraded part, the amount of gas produced from the slowly decomposed part, gas production rate and total gas production are easily interpretable and meaningful values in terms of animal nutrition. Ignoring residual values in model selection will lead to erroneous determinations and erroneous interpretations. It would be more statistically accurate to consider one or more of the model comparison criteria such as Durbin Watson, deviation factor, accuracy factor, Akaikle information criterion and Bayesian information criterion, which take into account the error terms of the models, together with other criteria.

4. Conclusion

As a result, it was determined that the models used could give different results in different feed sources, in other words, the models showed different reactions. For this reason, the use of more than one model in gas production curves is extremely important in choosing the right model and naturally in making correct interpretations and determinations. In addition, in this study, it was determined that fit criteria such as Durbin-Watson, Bias factor, accuracy factor, Akaikle information criterion and Bayesian information criterion based on error terms are extremely effective in model selection. Considering all the criteria, it was concluded that statistically models other than Logistic and Verhulst models can be easily used in modeling in vitro gas production curves.

Author Contributions

The percentage of the author contributions is presented below. The author reviewed and approved the final version of the manuscript.

	M.Ş.
C	100
D	100
S	100
DCP	100
DAI	100
L	100
W	100
CR	100
SR	100
PM	100

C=Concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision, PM= project management.

Conflict of Interest

The author declared that there is no conflict of interest.

Ethical Consideration

Ethics committee approval was not required for this study because of there was no study on animals or humans.

References

Bayazıt M, Şahin M, Tolun T. 2022. Modeling of in vitro gas production. BSJ Agri, 5(3): 260-264.

Brody S. 1945. Bioenergetics and growth; with special reference to the efficiency complex in domestic animals. Reinhold, Oxford, UK, pp: 254.

Canbolat Ö, Kamalak A, Efe E, Şahin M, Özkan ÇÖ. 2005. Effect of heat treatment on in situ rumen degradability and in vitro gas production of full-fat soybeans and soybean meal. South African J Anim Sci, 35(3): 186-194.

Canbolat Ö, Özkan ÇÖ, Kamalak A. 2007. Effects of NaOH treatment on condensed tannin contents and gas production kinetics of tree leaves. Animal Feed Sci Technol, 138(2): 189-194.

Cankaya S, Sahin M, Abaci SH. 2014. Comparison of wood and cubic spline models for the first lactation curve of jersey cows. J Anim Plant Sci, 24(4): 1018-7081.

Getachew G, Makkar HPS, Becker K.1998. The in vitro gas coupled with ammonia measurement for evaluation of nitrogen degradability in low quality roughages using incubation medium of different buffering capacity. J Sci Food Agric, 77: 87-95.

Gök Y, Şahin M, Yavuz E. 2021. Bazı sığır irklarinda bireysel laktasyon eğrisi modellerinin karşılaştırmalı olarak incelenmesi. KSU J Agri Nat, 24(5): 1118-1125.

Groot JCJ, Cone JW, Williams BA. 1996. Debersaques, F.M.A.; Lantinga, E.A. Multiphasic analysis of gas production kinetics for in vitro fermentation of ruminant feeds. Anim Feed Sci Technol, 64: 77-89.

Kamalak A, Canbolat Ö, Gürbüz Y, Özay O, Özkan ÇÖ, Sakarya M. 2004. Chemical composition and in vitro gas production characteristics of several tannin containing tree leaves. Livestock Res Rural Devel, 16(6): 60-67.

Korkmaz M, Uckardes F, Kaygısız A. 2011. Comparison of wood, gaines, parabolic, hayashi, dhanno, and polynomial, models for lactation season curve of simmental cows. J Anim Plant Sci, 21(3): 448-458.

Lopez S, France J, Dhanoa MS, Mould F, Dijkstra J. 1999. Comparison of mathematical models to describe disappearance curves obtained using the polyester bag technique for incubating feeds in the rumen. J Anim Sci, 77: 1875-1888.

Orskov ER, Mcdonald I.1979. The estimation of protein degradability in the rumen from incubation measurements weighted according to rate of passage. J Agri Sci, 92: 499-503.

Özkan ÇÖ, Şahin M. 2006. Comparison of In situ dry matter degradation with in vitro gas production of oak leaves supplemented with or without polyethylene glycol (PEG). Asian-Australasian J Anim Sci, 19(8): 1120-1126.

Richards FJ. 1959. A flexible growth function for empirical use. J Exp Bot, 10: 290-301.

Sahin M, Guven İ, Ozkan CO, Atalay AI, Tatliyer A. 2011. Comparison of some mathematical models used in gas production technique. J Anim Vet Adv, 10(18): 2465-2469.

SAS. 1999. The SAS System for Windows. Release 8.0.1. SAS Institutue Inc, Cary, US.

Schofield P, Pitt RE, Pell AN. 1994. Kinetics of fiber digestion from in vitro gas production. J Anim Sci, 72: 2980-2991.
Tahtalı Y, Sahin M, Bayburt L. 2020. Comparison of different growth curve models in Romanov lambs. Kafkas Univ Vet Fak Derg, 26(5): 609-615.
Üçkardeş F, Efe E. 2014. Investigation on the usability of some mathematical models in vitro gas production techniques. Slovak J Anim Sci, 47: 172-179.