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ANALYSING GROWTH PATTERNS OF SELECTED TURKISH OAT CULTIVARS USING SIGMOIDAL MODELS

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ABSTRACT

Increasing popularity of oat was accompanied with the introductions of many new cultivars for the last few decades. The aim of this study was to characterize the growth and developments of Kahraman, Kucukyayla, Yeniceri, Sebat, Otag and Dirilis oat cultivars using sigmoidal growth models. Growth data comprised of weekly observations of dry weights and growth stages with three samplings for two consecutive years. Results indicated that the growing season were the determining factor for the dry matter accumulation until the stem elongation stage since genotype differences became apparent only in the later stages. Sigmoidal growth models were successfully fitted to the growth data, and allowed for further evaluations. Goodness of fit statistics implied that Logistic, Logistic Power and Ratkowsky models were the best fitting growth models to explain dry matter accumulations of oat cultivars. Analysis also showed that Otag, Yeniceri and Sebat cultivars reached the highest dry matter accumulations. Point of inflections on the Logistic models indicated that Kucukyayla and Kahraman were the earliest cultivars in the Marmara region. Comparison of cultivars by using the growth models proved to be informative in terms of understanding the genotypic variation.

Keywords: Dry matter accumulation, earliness, growth models, Marmara, oat, Turkey

INTRODUCTION

Oat (*Avena sativa* L.) is prominent for feed and grain for the Mediterranean environment. Oat is grown annually and can be sown in both autumn and spring, former being the usual for the temperate regions. In addition to its traditional usage as a fodder crop, oat grain also became an area of interest in the coming years. This is due to relatively recent discovery of its dietary benefits. Oat grain is reported to have a unique quality, often regarding to a high oil, micronutrient, souble fibre and beta glucan contents (Welch, 2012; Loskutov et al., 2021). Quality of oat grain, especially the high beta glucan contents are linked to reduce blood cholesterol levels and improve hemostatic factors, further improving the cardiovascular health (Tosh and Bordenave, 2020). Therefore, the role of oat grain as food are no longer restricted to oatmeals. Oat grain is utilized in the food industry in a variety of products including whole grain, flour, bakery products, food supplements and even oat milk as a coffee additive (Onning et al., 1998; Rasane et al., 2015).

Oat has always been a prominent cereal in Turkish agriculture. Oat breeding effords in Turkey for the last 20 years also seems to prioritize grain related traits over vegetative growth (Hısır et al. 2012; Hocaoglu and Akcura, 2020). In the literature of agronomic researches conducted in Turkey, Turkish oat cultivars are mainly compared by their grain yields and yield components when underlying biological mechanism remains unvisited. Comparing genotypes by the variation of their growth habits would provide insight about how genotypes differ from eachother (Karadavut, 2009). This comparison could also be useful from the standpoint of understanding the genotype environment interaction. Collection and statistical evaluation of a reliable growth data would not only reveal which genotypes are preferable for a given environment, but also potentially provide an insight about the underlying reasons.

A basic and effective way to evaluate plant growth is by implementing growth models. Using sigmoidal growth models to explain the biological growth has an impressively long history. Growth curves such as Logistic and Gompertz were known to be used in 19^{th} century (Bollen and Curran, 2006) which is remarkable since their original formulas and variations are still in use today. Sigmoidal models produce curves resembling a streched “S” that corresponds well with the process of biological growth in general, whether it is the growth of a population or an individual organism. Therefore, these curves can be configured for a given data – a process called “the curve fitting” – to allow us to evaluate our data statistically. Today, many available softwares can perform this by fitting several models on the given data and ranking the most suitable models by their coefficients of determination (R^2), lower error statistics and other indicators such as Akaike's information criterion (AICC) or Bayesian information criteria (BIC). These parameters can vary according to the analysis and usually referred to as to "Goodness of fit" statistics. Curve fitting also yields shape parameters that defines the fitted curve on the given data. Some shape parametes can have biological meanings – allowing us to evaluate genotypes or environments by comparing the differences in between their curves. Although growth analysis has and will have a much wider use in the future, these approaches are seen as the main reason behind the growing popularity of the use of growth models in agronomy.

The objective of the study was to compare the dry matter growth of several oat cultivars under Marmara region condition by using the sigmoidal growth models to better understand the variation among their growth habits.

MATERIALS AND METHODS

Field Trials

Field trials were conducted in the Unit of Agricultural Production and Research of Canakkale Onsekiz Mart University Faculty of Agriculture in Canakkale (Turkey) for two consecutive growth seasons (2019-2020 and 2020-2021). Oat cultivars Kahraman, Dirilis, Kucukyayla, Otag, Sebat and Yeniceri were used as plant material, all of which were generally considered as suitable for the Marmara region. Cultivars Kahraman, Kucukyayla, Otag and Yeniceri were registered as early cultivars when Dirilis and Sebat were classified as mid-early. Field trials were sown in 6 November 2019 and 13 November 2020 in the first and the second year, respectively. Field trial was arranged in Randomized Complete Block Design (RCBD) in split-plots with three replications where genotype and sampling times were arranged as the main and sub plots, respectively. Agronomic applications of both trials were consistent including plot sizes, sowing densities (550 plants m^{-2}), fertilization and weed management. Each plot included six plant rows arranged with 0.2 m space apart, covering a total of 6 m^2 of the area. Phosphorus were applied before sowing as 6 kg da^{-1} P_2O_5 in the diammonium phosphate (DAP) form when nitrogen from DAP were complemented with an additional ammonium sulfate application in the beginning of stem elongation stage to a total of 8 kg da^{-1} N (which coincided with the 14^{th} week of samplings in both years). Chlorsulfuron were used to control broad-leaved weeds while remaining weeds were controlled by hand.

Data Collection and Statistical Analysis

In order to identify the differences among varying growth patterns of oat cultivars, dry weights were monitored in a weekly base. Our aim was to assess the dry matter accumulations of oat cultivars with accuracy which required precision in the field measurements. In order to minimize the spatial variation within the plots, 300 plants were selected for sampling and marked from each plot after the emergence of the first leaf. This plant markings proved useful to guide the future plant samplings. In each sampling, growth stages of oats were assessed (Zadoks, 1974) for each plot, then 10 plants were randomly selected for plant height and number of tillers measurements. These measurements were used as the preliminary evaluation criteria reflecting the current sitation of the plot, after which the outliers were excluded from the evaluation. Finally, above-ground biomasses of randomly selected 3 plants were collected from the remaining plants. Fresh samples were dried in the drying oven for at least 48 hours in 105°C for dry weight measurements. Dry weight averages of each cultivar were used as the growth data which were recorded from the week when germinations were completed (Zadoks Scale 10) until the harvest maturity (Zadoks Scale 90). Total number of samplings varied between 26-28 weeks for the first year and 24-26 weeks in the second year.

Curve fitting on the field data identifies the growth patterns and yields several curve parameters that are biologically meaningful for us to use for comparison (Diel et al., 2020). In this study, growth data were fitted to the most commonly used sigmoidal models and results were evaluated with Curve Expert Professional v. 2.7.3 software (Hyams, 2010). Model efficiency were compared using standard error, R Square and corrected Akaike's information criterion (AICC). Random distribution of the residuals were tested by Wald-Wolfowitz runs test, results of which indicated that run patterns of the residuals were unlikely for all curves (<%5) meaning that the residuals were randomly distributed (Hyams, 2020). Since there was an excessive amount of output data, only three best fitting models were reported for each graph. Curve parameters *a*, *b* and *c* were derived from Curve Expert Professional v. 2.7.3 when point of inflection (PI) and weight at the point of inflection (WIP) were calculated manually according to the Wen et al. (2019).

RESULTS AND DISCUSSION

Growth curves of six oat cultivars for two growing seasons were presented in Figures 1- 12. Each growth data fitted to Gompertz, 3 Parameter Logistic, Logistic Power, MMF, Ratkowsky, 3 Parameter Richards and 3 Parameter Weibull models separately. In the Figures 1-12, weekly dry weight measurements of oat cultivars were presented with the standard error (Std Err), R Square and corrected Akaike's information criterion (AICC) of three best fitting models. Logistic, Gompertz, Logistic Power and Ratkowsky models displayed the overall best results with the highest R Square and lowest AICC values. First 10-15 weeks showed no significant increase of dry weight for any oat cultivar because of the winter dormancy since trials were sown in autumn. Stem elongation stage began in 17^{th} week for all cultivars in the first year and $17\text{-}20^{th}$ weeks in the second year, indicating that the date of stem elongation could be driven more by the environmental factors rather than genotypic variation. Rising temperatures and precipitation of the early weeks of the spring in the Mediterranean climate seemed to have triggered a rapid growth, which usually began during the last weeks of the tillering stage (Figures 1-12). Rapid increase of dry weight gain for all cultivars began in the 15th week in the first year and 15 – 18th weeks in the second year. Differences among the growth patterns of oat cultivars became evident in this period.

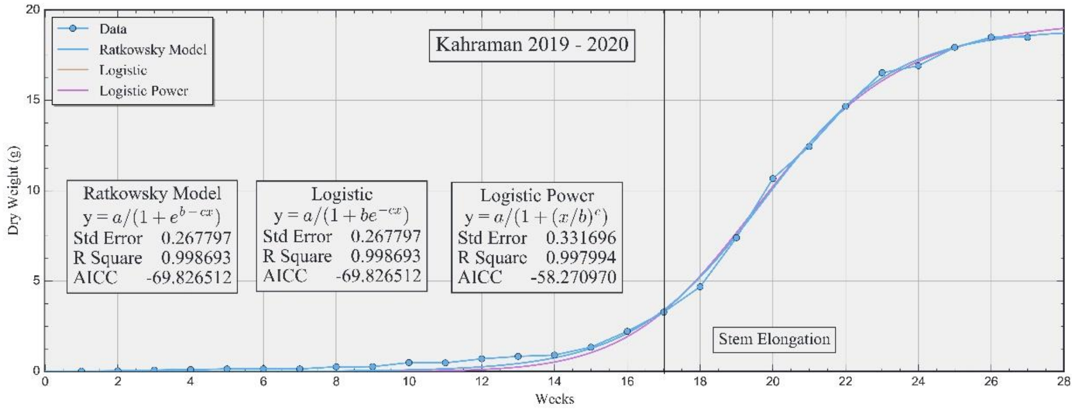

Figure 1. Identifying the dry weight increase of Kahraman oat cultivar with the sigmoidal curves (first year).

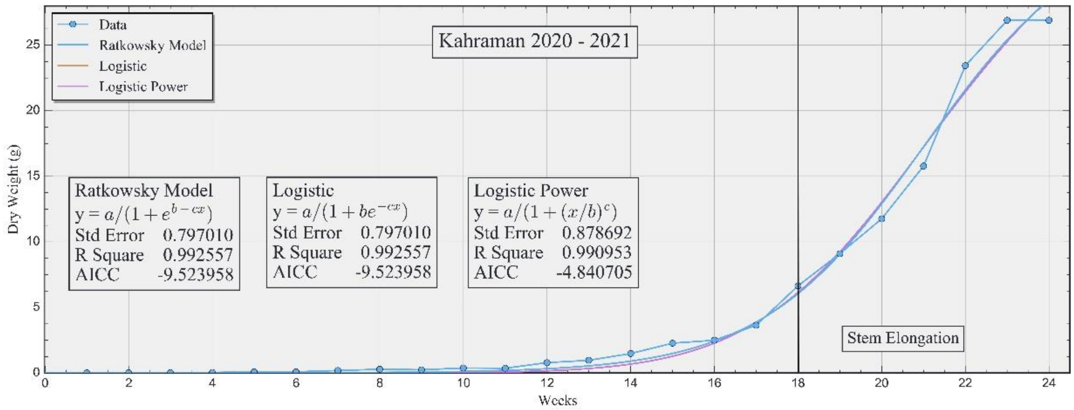

Figure 2. Identifying the dry weight increase of Kahraman oat cultivar with the sigmoidal curves (second year).

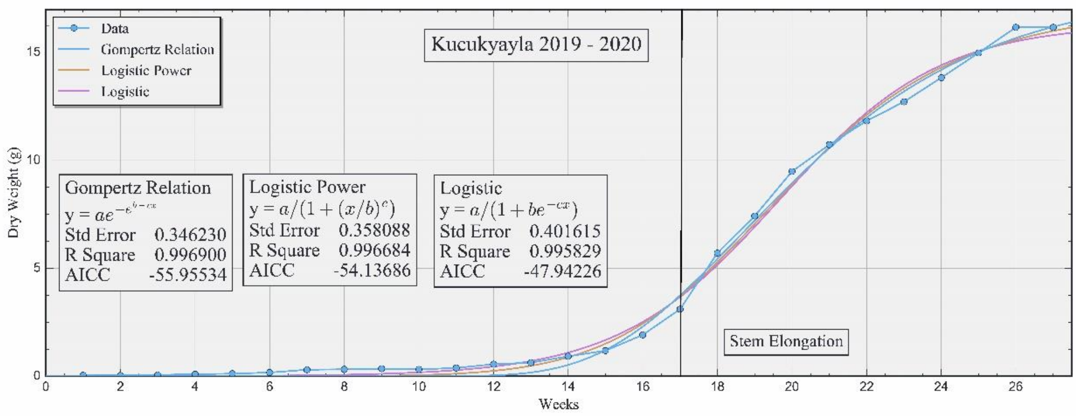

Figure 3. Identifying the dry weight increase of Kucukyayla oat cultivar with the sigmoidal curves (first year).

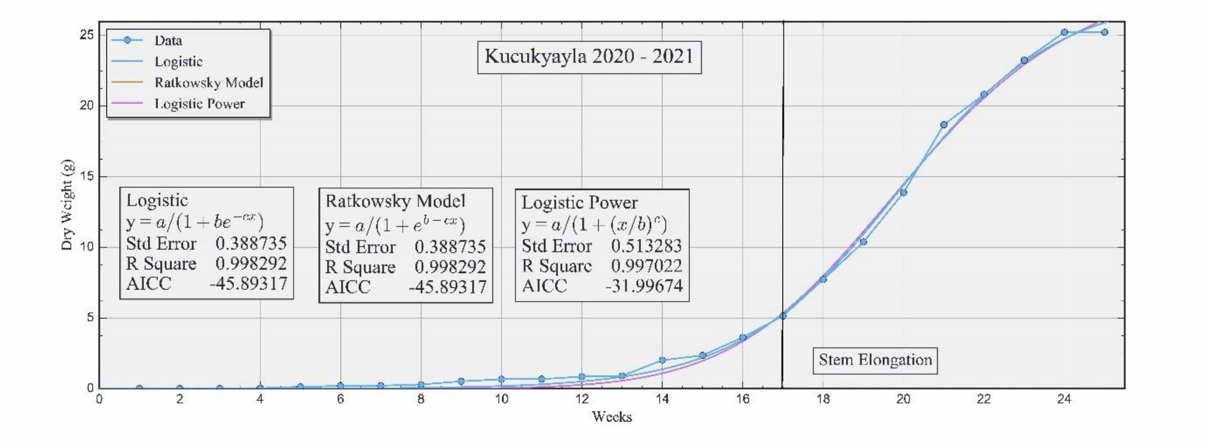

Figure 4. Identifying the dry weight increase of Kucukyayla oat cultivar with the sigmoidal curves (second year).

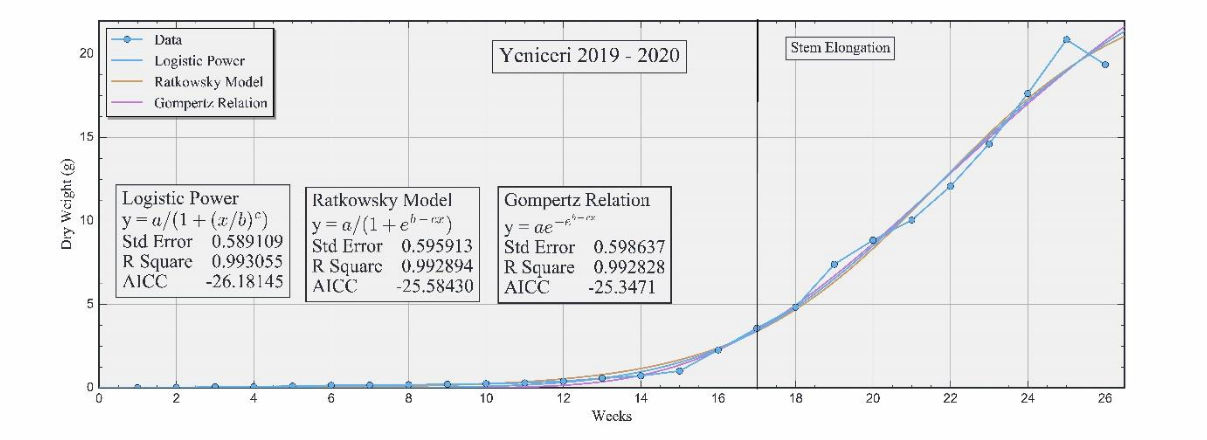

Figure 5. Identifying the dry weight increase of Yeniceri oat cultivar with the sigmoidal curves (first year).

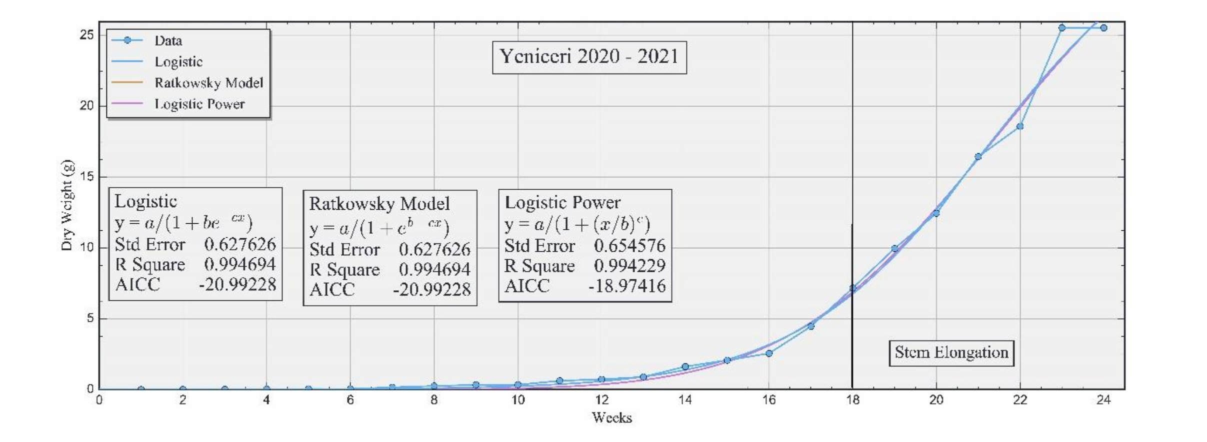

Figure 6. Identifying the dry weight increase of Yeniceri oat cultivar with the sigmoidal curves (second year).

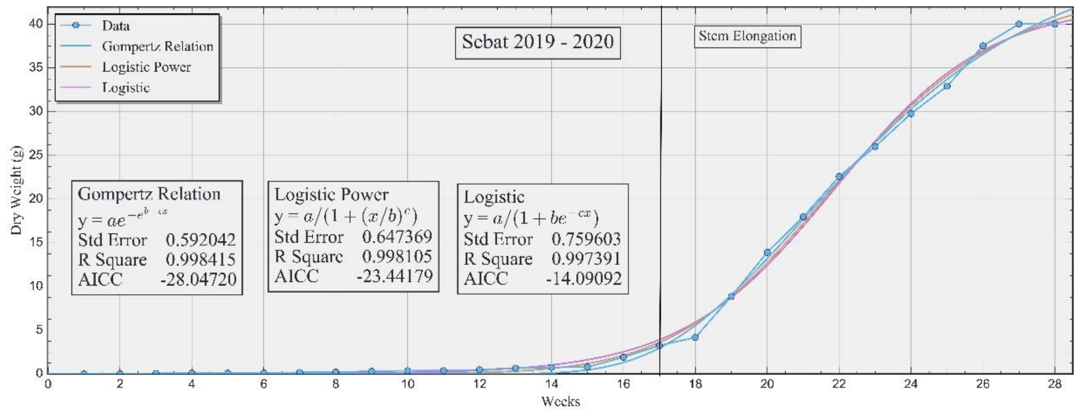

Figure 7. Identifying the dry weight increase of Sebat oat cultivar with the sigmoidal curves (first year).

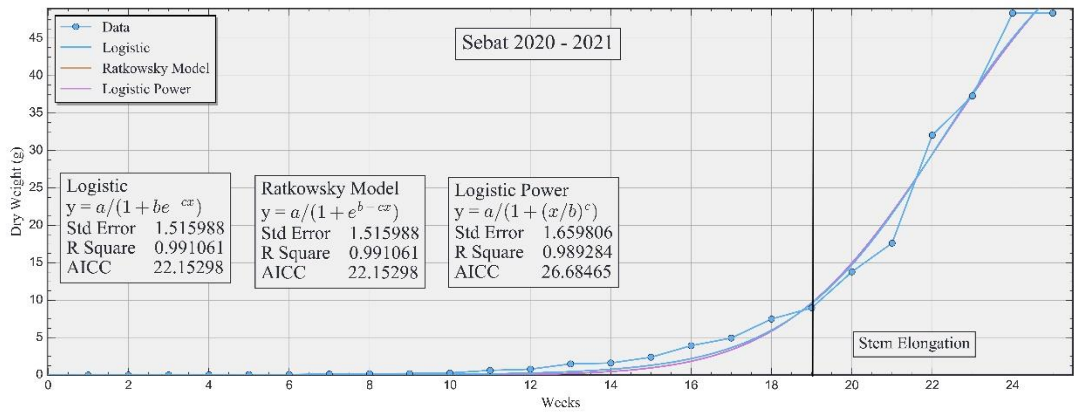

Figure 8. Identifying the dry weight increase of Sebat oat cultivar with the sigmoidal curves (second year).

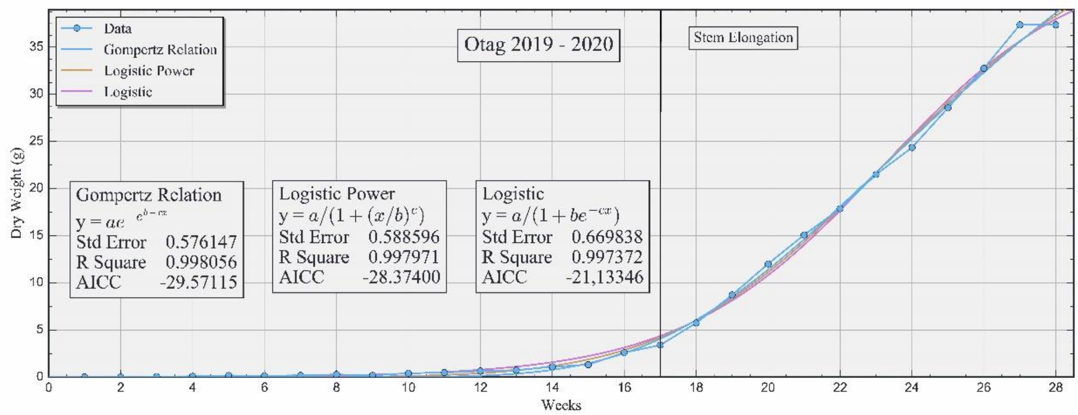

Figure 9. Identifying the dry weight increase of Otag oat cultivar with the sigmoidal curves (first year).

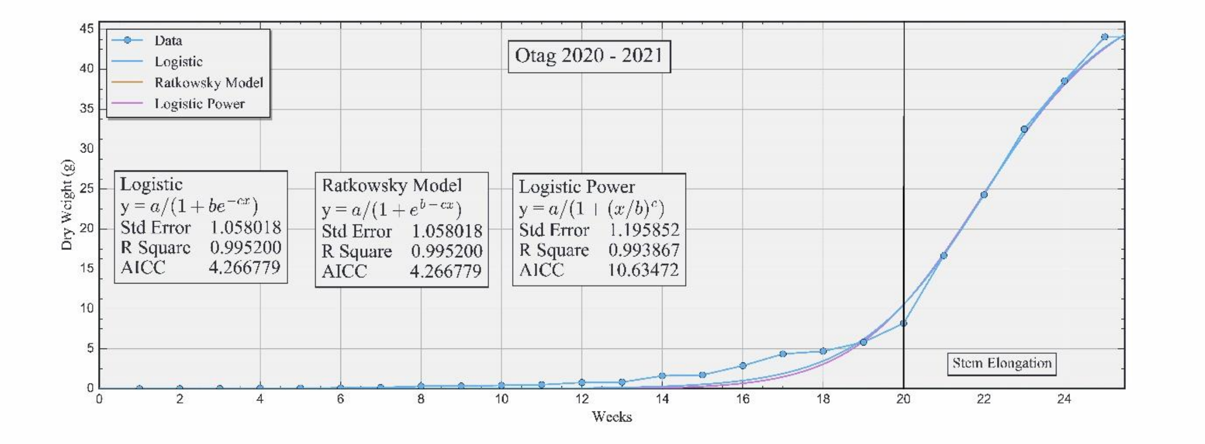

Figure 10. Identifying the dry weight increase of Otag oat cultivar with the sigmoidal curves (second year).

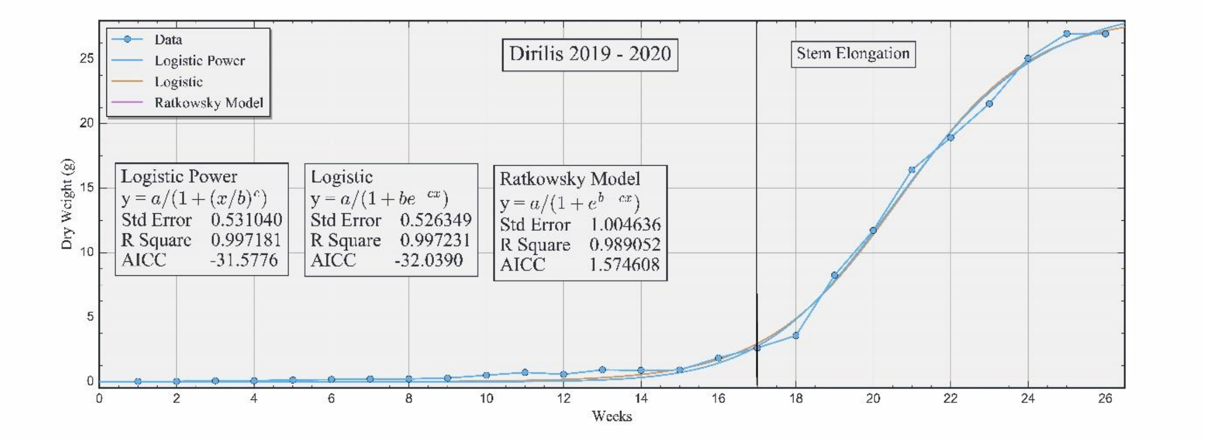

Figure 11. Identifying the dry weight increase of Dirilis oat cultivar with the sigmoidal curves (first year).

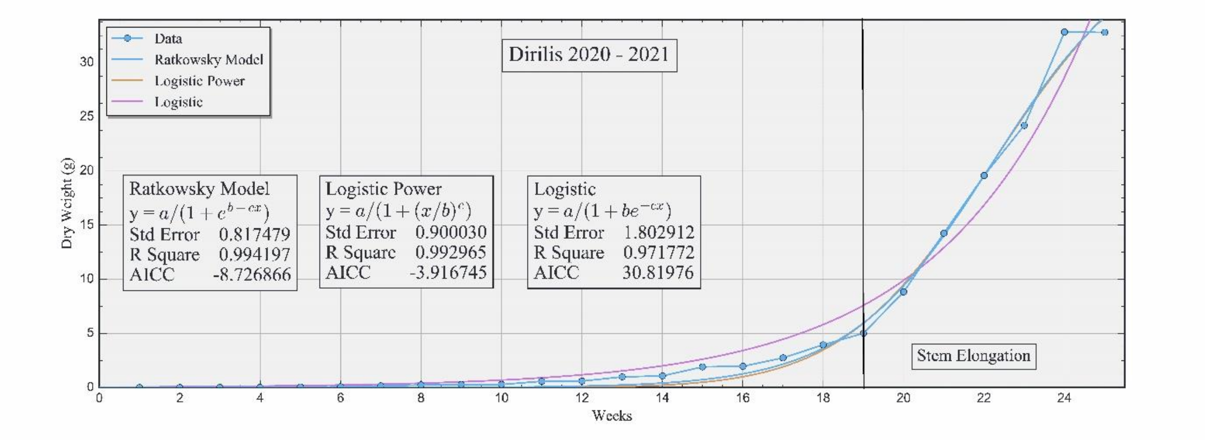

Figure 12. Identifying the dry weight increase of Dirilis oat cultivar with the sigmoidal curves (second year).

In order to evaluate these differences statistically, estimated curve parameters *a*, *b*, *c* were presented in Table 1. In growth analysis, parameter *b* is usually referred as a biological constant when parameters *a* and *c* are often attributed with biological meanings. Parameter *a* is associated with the maximum value of the curve when *c* is reported to reflect the growth rate in certain sigmoidal models (Tjørve, 2003; Keskin et al., 2009) According to the results, parameter *a* varied between 16.33 (Kucukyayla, Logistic) and 62.48 (Otag, Gompertz) in the first year and 27.86 (Kucukyayla, Logistic) and 63.34 (Sebat, Logistic Power, Table 1). Logistic model of Dirilis cultivar in the second year is excluded from this evaluation, parameters of which were outliers possibly due to reduced efficiency of the Logistic model as a result of unusually high growth rate observed in the latest weeks (Table 1, Figure 12). In this study, parameter *a* reflects the theoretical maximum dry weights of oat cultivars. Highest dry weight production were observed in Sebat and Otag cultivars in both years. It should be noted that maximum dry weights of oat cultivars were obtained individually from the tiller groups, therefore it is not an indication of the biological yield which reflects the dry weights collected from an area.

Table 1. Curve parameters of the sigmoidal models given in Figures 1-12

Genotype / Year / Model	a	b	c	PI*	WIP**	*Genotype / Year / Model*	a	b	c	PI	WIP
Kahraman						**Sebat**					
2019-2020						*2019-2020*					
Ratkowsky	18.923	10.920	0.553			Gompertz	48.548	5.356	0.255	6.593	17.860
Logistic	18.923	55284.724	0.553	19.748	9.461	Log Power	44.965	22.105	-9.294		
Log Power***	19.518	19.811	-10.351			Logistic	42.341	28611.734	0.469	21.873	21.170
2020-2021						*2020-2021*					
Ratkowsky	34.364	10.858	0.517			Logistic	62.072	143063.086	0.535	22.183	31.036
Logistic	34.364	51925.439	0.517	20.985	17.182	Ratkowsky	62.072	11.871	0.535		
Log Power	38.633	21.492	-9.395			Log Power	69.341	22.648	-10.376		
Kucukyayla						**Otag**					
2019-2020						*2019-2020*					
Gompertz	17.976	5.052	0.271	5.983	6.613	Gompertz	62.481	3.690	0.158	8.267	22.985
Log Power	17.145	5.444	0.296			Log Power	52.295	24.184	-6.890		
Logistic	16.329	9348.121	0.465	19.658	8.164	Logistic	44.624	4196.901	0.360	23.167	22.312
2020-2021						*2020-2021*					
Logistic	27.862	22440.710	0.504	19.865	13.931	Logistic	49.172	1291554.72	0.639	22.033	24.586
Ratkowsky	27.862	10.019	0.504			Ratkowsky	49.172	14.071	0.639		
Log Power	29.843	20.129	-9.002			Log Power	51.169	22.144	-13.266		
Yeniceri						**Dirilis**					
2019-2020						*2019-2020*					
Log Power	28.253	22.5	-7.008			Log Power	29.537	20.8	-11.346		
Ratkowsky	24.235	8.450	0.390			Logistic	28.397	180881.051	0.585	20.682	14.198
Gompertz	34.012	3.723	0.170	7.712	12.512	Ratkowsky	28.397	12.106	0.585		
2020-2021						*2020-2021*					
Logistic	33.935	11074.126	0.440	21.161	16.968	Ratkowsky	41.355	12.378	0.558		
Ratkowsky	33.935	9.312	0.440			Log Power	45.269	22.545	-11.049		
Log Power	40.856	22.150	-7.671			Logistic	$-1.5*10^{-9}$	$-3.1*10^{-10}$	0.2657		

*PI: Point of inflection, **WPI: Weight at the point of inflection, *** Log Power: Logistic Power

Other curve parameter, the parameter *c* can be associated with the growth rate in several models, although it is not often used to deduce biological meanings. Individual comparison of the curve parameters are not always meaningful since curve parameters often reflect the shape of the equations collectively. Parameter *a* in Logistic model, for example, reflects the maximum dry weight by being the only parameter related to the upper asymptote when other features of the curve such as overall shape or y-axis intersection are represented by parameters *b* and *c* together (Tjørve, 2003). Therefore, biological interpretations are restricted to several models and parameters.

Another biologically meaningful parameter that can be calculated from the equations of some models is the point of inflection (PI). Logistic and Gompertz models both have a fixed point of inflection (PI) where the rate of growth gets its maximum value (Goshu and Koya, 2013). PI of the Logistic curve is calculated with the equation "*a*/2", which remarks the week where plants reaches %50 of the maximum dry weight. PI of the Gompertz model is calculated with the formula "*a*/*e*" with *e* being the mathematical constant; therefore PI of Gompertz is located roughly around %37 of the total growth duration (Duan et al., 2015). Therefore, comparison PI can only be meaningful within the different curves of the same model.

In this case, PI should provide us an idea about how early oat cultivars reach to the maximum rate of dry matter accumulation (which is expected to coincide around late stem elongation stage) in Marmara region. Logistic model provided to be one of the best fitting models to our data which can be seen in high R square and low AICC values in Figures 1-12. Logistic model were constantly among the best fitting models with the only exception being the Dirilis cultivar on the second year. This allowed us to compare the PI and the dry weights at PI (WPI) values of Logistic models from each curve (Table 1). Cultivars that began rapid growing earlier than others are expected to have a lesser PI. In Table 1, PI varied between the weeks 19.66 (Kucukyayla) and 23.17 (Otag), both from the results of the first year (Table 1). Otag consistently had the highest PI for each year, making it the latest to develop rapid dry weight increase in both years. Cultivar Otag began rapid dry weight accumulation in later weeks when compared to other figures of the same year which can also be seen in Figures 11 and 12. Despite its late boom, Otag cultivar had the highest Parameter *a* value in the first year and second highest in the second year, indicating a faster growth in later periods. Other cultivars such as Yeniceri and Sebat also consistently had higher PI, thus were also late developing cultivars.

Cultivars with the lowest PI for both years were Kucukyayla and Kahraman with PI values ranging between 19.65 and 20.98 weeks (Table 1). PI of these cultivars were above 20 weeks for both years with the exception of Kahraman in second year. Variation of PI among cultivars may not seem significant at first, but in practice, each week can be critical and therefore may decisively affect the plant growth. Cultivar differences in terms of their ability to initiate rapid dry weight increase earlier is important for spring cultivation (Buerstmayr et al., 2007) but it may also gain interest for the Mediterranean climate. In a foreseeable future, growing season for winter crops are expected to be shortened (Saadi et al., 2015) and occurrences of heat waves to be increased (Kuglitsch et al., 2010) due to the climate change, which might restrict the growth of late-developing cultivars.

In conclusion, our results indicated that sigmoidal growth models explained oat dry weight increases with the R squares ranging from 0.971772 to 0.998693. This success of the curve fitting process on the growth data of oat makes way for improving our understanding of oat growth. We concluded that Logistic, Logistic Power and Ratkowsky models were the best fitting sigmoidal models for our data. Our comparison of oat cultivars implies that cultivars Otag, Yeniceri and Sebat generated higher maximum dry weights per plant samples. In addition, Otag and Sebat developed later for Marmara Region when Kucukyayla and Kahraman were the earliest cultivars in terms of dry matter accumulation. Although later developing cultivars seemed to accumulate higher dry weights, a larger set of genotypes would be needed to reach a definitive conclusion. In terms of expected consequences of global warming, earlier developing cultivars such as Kahraman and Kucukyayla may provide more consistent yields in the future.

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