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Francieli de Lima Tartaglia

PLANEJAMENTO EXPERIMENTAL E DESCRIÇÃO DA PRODUÇÃO DE ERVILHA

Santa Maria, RS
2021

Francieli de Lima Tartaglia

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Dissertação apresentada ao Curso de Pós-Graduação em Agronomia, da Universidade Federal de Santa Maria (UFSM, RS), como requisito parcial para a obtenção do título de **Mestre em Agronomia**.

Orientador: Prof° Dr°. Alessandro Dal' Col Lúcio

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Santa Maria, RS
2021

DEDICATÓRIA

Aos meus pais Osmar Tartaglia e Maria das Graças de Lima Tartaglia que sempre foram grandes incentivadores. Aos meus irmãos Francilene Tartaglia, Francismar Tartaglia e Vanderley Tartaglia

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“Não voes como ave de capoeira, quando podes subir como as águias”.

(São Josemaria Escrivá de Balaguer)

RESUMO

PLANEJAMENTO EXPERIMENTAL E DESCRIÇÃO DA PRODUÇÃO DE ERVILHA

AUTORA: Francieli de Lima Tartaglia
ORIENTADOR: Alessandro Dal’Col Lúcio

A ervilha é uma leguminosa de cultivo anual, seu grão apresenta grande valor nutricional, sendo uma importante fonte de nutrientes para a alimentação humana. Assim, devido à importância desta olerícola várias pesquisas são realizadas. No entanto, informações para a condução de experimentos com elevada precisão experimental são escassos para a cultura, bem como informações de aplicação de modelos de regressão não linear para a descrição da sua produção. Neste sentido, este trabalho tem como objetivo avaliar as relações de causa e efeito entre as variáveis de produção de ervilha e verificar se elas seguem a mesma tendência entre as colheitas e épocas de cultivo, estimar o tamanho de amostra, tamanho de parcela, o número de repetições e modelar o ciclo da produção da cultura da ervilha. Os ensaios de uniformidade foram conduzidos a campo nos anos de 2016, 2017 e 2018 na área experimental do Departamento de Fitotecnia da Universidade Federal de Santa Maria – UFSM, no município de Santa Maria – RS. A cultivar utilizada foi a Ervilha Grão 40. Foram mensurados os caracteres de massa e número total de vagens, comprimento das vagens, números e massa de grãos por vagens. As relações entre as variáveis foram estimadas pelas correlações lineares de Pearson e, posteriormente, desdobrou-se os efeitos diretos e indiretos pela análise de trilha. Realizou-se ainda análise de correlações canônica entre o grupo de variáveis de vagem e variáveis de grão. O tamanho de parcela, o tamanho de amostra e número de repetições foram estimados, e ajustou-se o modelo não linear logístico para caracterizar a produção. Os resultados mostram que a produção de ervilha sofre interferência das condições ambientais, porém, apresentou a mesma tendência nas relações entre as variáveis, nas diferentes colheitas e épocas de cultivo. As variáveis massa de vagens e números de grãos são as variáveis com maiores relações de causa e efeito sobre a massa de grãos e podem ser utilizadas para a seleção indireta de plantas mais produtivas. Plantas com menor massa de vagens proporcionam vagens com menor número de grãos e menor massa de grãos. O tamanho de parcela para avaliar o número de vagens por planta e massa de vagens por planta para a cultura da ervilha é de oito e nove plantas, respectivamente. O tamanho de amostra para a avaliar o número de vagens por planta e massa de vagens por planta é de oito plantas na direção da linha com uma semi-amplitude do intervalo de confiança de 20% da média. Para as variáveis número de vagens por plantas e massa de vagens por planta de ervilha são necessários 10 e 12 repetições, respectivamente, para avaliar até 20 tratamentos no delineamento de blocos ao acaso e no delineamento blocos incompletos com até 100 tratamentos para diferenças significativas de 35% entre médias de tratamentos. Pelo ajuste do modelo logístico, verificou-se que a época 1 foi a mais produtiva, apresentando incrementos máximos na produção em menor período (592,5 °C dias^{-1} para produzir 119,52g), ocasionando um pico de produção elevado em relação as outras épocas analisadas.

Palavras-chave: *Pisum sativum*. Análise de trilha. Correlação canônica. Tamanho de parcela. Tamanho de amostra. Número de repetições. Modelos não lineares. Modelo logístico.

ABSTRACT

EXPERIMENTAL PLANNING AND DESCRIPTION OF PEA PRODUCTION

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The pea is a legume cultivated annually, its grain has great nutritional value, being an important source of nutrients for human consumption. Thus, due to the importance of this vegetable garden, several researches are carried out. However, information for conducting experiments with high experimental precision is scarce for culture, as well as information on the application of nonlinear regression models to describe their production. In this sense, this work aims to evaluate the cause-and-effect relationships between the variables of pea production and verify if they follow the same trend between harvests and growing seasons, estimate the sample size, plot size, the number of repetitions and model the production cycle of the pea crop. Uniformity tests were conducted in the field in the years 2016, 2017 and 2018 in the experimental area of the Departament of Plant Science of the Federal University of Santa Maria - UFSM, in the municipality of Santa Maria - RS. The cultivar used was the Pea Grain 40. The characters of mass and total number of pods, length of pods, numbers and mass of grains per pod were measured. The relationships between the variables were estimated by Pearson's linear correlations and, later, the direct and indirect effects were unfolded by the trail analysis. Canonical correlation analysis was also carried out between the group of pod variables and grain variables. The plot size, sample size and number of repetitions were estimated, and the logistic nonlinear model was adjusted to characterize the production. The results show that pea production is affected by environmental conditions, however, it presented the same trend in the relationships between variables, in different harvests and growing seasons. The pod mass and grain number variables are the variables with the highest cause and effect relationships on the grain mass and can be used for the indirect selection of more productive plants. Plants with a lower pod mass provide pods with fewer grains and less grain mass. The plot size for evaluating the number of pods per plant and the mass of pods per plant for pea cultivation is eight and nine plants, respectively. The sample size for evaluating the number of pods per plant and the mass of pods per plant is eight plants in the direction of the line with a semi-amplitude of the confidence interval of 20% of the mean. For the variables number of pods per plant and pod mass per pea plant, 10 and 12 repetitions are required, respectively, to evaluate up to 20 treatments in the randomized block design and in the incomplete block design with up to 100 treatments for significant differences of 35 % between treatment averages. By adjusting the logistic model, it was found that season 1 was the most productive, with maximum increases in production in a shorter period (592.5 °C days^{-1} to produce 119.52g), causing a high production peak in relation to the other periods analyzed.

Keywords: *Pisum sativum*. Path analysis. Canonical correlation. Plot size. Sample size. Number of repetitions. Non-linear models. Logistic model.

SUMÁRIO

1 INTRODUÇÃO

A ervilha (*Pisum sativum* L.) é uma leguminosa de cultivo anual, cuja origem é imprecisa. Primeiramente foi consumida na forma de grãos secos por um longo tempo e apenas a partir do século XVIII passou a ser utilizada na alimentação humana em forma de ervilha verde recém colhida (SCHIAVON et al., 2018). O grão apresenta grande valor nutricional, chegando a alcançar 29% de proteína, sendo importante fonte de nutrientes para a alimentação humana (CANNIATTI-BRAZACA, 2006).

A busca por alimentação mais saudável está impulsionando a produção mundial da ervilha, que tem aumentado ao longo dos anos, atingindo uma produção de 21,2 milhões de toneladas de ervilha verde em 2,743,867 hectares colhidos em 2018 (FAOSTAT, 2020). No Brasil em 2018 foram colhidas 2813 toneladas de ervilha seca em uma área de 837 hectares, o que em relação ao mercado mundial é inexpressiva. Porém para ervilha verde, não foram encontrados dados de produção, área plantada e área colhida (FAOSTAT, 2020).

Apesar da grande importância nutricional da ervilha para a alimentação humana, os estudos com a cultura são escassos. Na literatura não foram encontradas informações sobre técnicas experimentais como o tamanho de amostra e tamanho de parcela para a condução de experimentos com elevada precisão experimental, bem como informação de aplicação de modelos de regressão não linear para a descrição da produção da cultura.

Em qualquer área de pesquisa, o planejamento experimental é a principal fase da realização de experimento, pois é nessa fase que se determina praticamente todos os procedimentos que serão realizados durante o experimento, auxiliando o pesquisador no desenvolvimento do mesmo. No planejamento, o pesquisador deve apresentar soluções para o problema apresentado, além de estar ciente das fontes de variações que podem ocorrer em seu experimento, levando em consideração o nível de significância definido e o desenho experimental utilizado nos procedimentos estatísticos (LÚCIO; SARI, 2017; STORCK et al., 2011).

A qualidade de um experimento pode ser avaliada pela magnitude do erro experimental, o qual não pode ser eliminado completamente, mas conhecendo as suas causas podem ser contornadas mantendo em níveis aceitáveis. Algumas situações que podem ser consideradas fontes de erro são a heterogeneidade das unidades experimentais, heterogeneidade do material experimental, heterogeneidade na aplicação dos tratos culturais, competição intraparcelar e interparcelar, pragas, doenças e plantas daninhas. De acordo com Lúcio & Sari (2017) o erro experimental pode aumentar devido a problemas no planejamento e implementação de experimento, provocando baixa precisão experimental com resultados não muito confiáveis. Assim, tecnologias que permitem o controle do erro experimental se tornam interessantes para manter a precisão e a confiabilidade das inferências em um nível adequado.

O tamanho de amostra, o tamanho de parcela e o número de repetições são determinações importantes que devem ser consideradas quando se tem por objetivo aumentar a confiabilidade do experimento, sendo que, devem ser definidos no planejamento experimental (LÚCIO; SARI, 2017). Quando os tamanhos de amostras e parcelas ainda não foram estimados para uma determinada cultura, geralmente são utilizados tamanhos indicados para culturas similares ou, ainda, são estipulados de forma empírica pelo próprio pesquisador. Esta forma de definição inflaciona o erro experimental, pois os tamanhos de amostra e parcela variam de acordo com cultura utilizada. Vários trabalhos foram realizados em diversas culturas para estimar os tamanhos de amostra e de parcela (BRUM et al., 2015; LÚCIO et al., 2003, 2012; SANTOS et al., 2012; TOEBE et al., 2014). Para a ervilha forrageira (*Pisum sativum* subsp. *arvense* (L.) Poir) já foi determinado o tamanho de parcela e número de repetições para a massa verde (CARGNELUTTI FILHO; SILVEIRA; SPANHOLI, 2015), porém para as variáveis massa total de grãos e número total de grãos para a cultura da ervilha não foram encontrados resultados na literatura.

O uso de técnicas de análises bivariada e multivariada como a análise de correlação de Pearson, análise de trilha e correlação canônica, são essenciais para o conhecimento da natureza e magnitude das correlações entre os caracteres, principalmente se a seleção de um deles apresenta dificuldade, devido a baixa herdabilidade, ou problemas de medição e identificação (CRUZ; REGAZZI; CARNEIRO, 2012). A análise de trilha permite realizar o desdobramento do coeficiente de correlação em efeitos diretos e indiretos de caracteres sobre uma variável básica (CRUZ; REGAZZI; CARNEIRO, 2012; WRIGHT, 1921). A correlação canônica permite avaliar as inter-relações entre dois complexos determinados por um número aleatório de caracteres, ou seja, existe dois conjuntos de variáveis em que se busca a máxima correlação entre ambos (CRUZ; REGAZZI; CARNEIRO, 2012). Dessa forma, a análise de trilha e a correlação canônica podem complementar os estudos via correlações e proporcionar uma análise mais detalhada dos fatores resultantes em uma correlação, podendo ser utilizada com mais precisão no momento da seleção indireta.

Outro fator importante para o planejamento experimental é o conhecimento do ciclo produtivo da cultura, pois, a partir desse conhecimento, é possível realizar o manejo adequado, utilizando informações relevantes que detectem possíveis problemas no crescimento e desenvolvimento da cultura. Essas informações podem ser obtidas a partir do emprego de modelos de regressão não lineares, pois estes apresentam parâmetros com interpretação biológica como o valor máximo da característica em questão e a velocidade do crescimento (MISCHAN; PINHO, 2014). Os modelos de regressão não lineares vêm sendo utilizados em diversas culturas como o feijão-de-vagem (LUCIO; NUNES; REGO, 2016), alho (REIS et al., 2014), tomate cereja (LÚCIO et al., 2016), abóbora e pimentão (LÚCIO; NUNES; REGO, 2015) a fim de modelar o ciclo de produção, porém para a cultura da ervilha não foi encontrado nenhum estudo na área.

2 ARTIGO 1 - LINEAR RELATIONSHIP BETWEEN PEA PRODUCTION CHARACTERS

Submetido para o periódico: Crop & Pasture Science
Situação: em avaliação

Linear relationship between pea production characters

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2.1 ABSTRACT

This work aims to evaluate the cause and effect relationships among pea production variables and determine if they follow the same trend between harvests and growing seasons. Uniformity tests were conducted in the field in the years 2016, 2017 and 2018. The variables analyzed were: mass and length of pods, number, and mass of grains per pod. The relationships among the variables were estimated by Pearson's linear correlations and, later, the direct and indirect effects were unfolded by path analysis. Canonical correlation analysis was also carried out between the group of pod variables and grain variables. Pea production showed the same trend in the relationships among variables in different harvests and growing seasons, suffering interference from environmental conditions. The variables pod mass and number of grains are the variables with the highest cause and effect relationships on the mass of grains and can be used for the indirect selection of more productive plants. Plants with a lower pod mass provide pods with a lower number of grains and less mass of grains, and it is necessary to produce plants with a greater pod mass to increase the productivity of pea grains.

Keywords: *Pisum sativum*, Pearson's correlations, path analysis, canonical correlations, productivity, cultivation environment.

2.2 INTRODUCTION

The pea (*Pisum sativum* L.) is a legume cultivated annually, whose origin is imprecise, but Ethiopia, the Mediterranean Basin, and Central Asia are considered the main points of origin

(Zohary and Hopf 1994; Cousin 1997). The grain has great nutritional value, reaching 29% protein, and is an important source of nutrients for human and animal food (Canniatti-Brazaca 2006; Schiavon *et al.* 2018).

It is generally grown in temperate regions, where temperatures are between 13 °C and 18 °C (Giordano 1997). Climatic factors such as temperature, radiation, irradiation and humidity are important for the growth and development of the crop, strongly influencing its production (Roro *et al.* 2016). Elevated temperatures during flowering and fruiting can adversely affect production (Hardwick 1988; Jeuffroy *et al.* 1990). Likewise, very low temperatures in the reproductive period also affect grain yield (Zhang *et al.* 2016), which can cause variability in the production of pods at different harvest times.

In crops with multiple harvests, fruits are harvested in different periods and may or may not show fruits suitable for harvesting, thus causing variability in the experiment (Lúcio *et al.* 2010). For crops such as *Cucurbita pepo*, heterogeneous variance between harvests was found due to climatic conditions, leading to rapid fruit growth in the winter/spring season and slow growth in the summer/autumn season (Lúcio *et al.* 2008). For the *Solanum lycopersicum* culture, heterogeneous variance was found in the fruit phytomass between the different harvests (Lúcio *et al.* 2010). For *Capsicum annuum*, significant variability in fruit production between crop lines was also found regardless of the growing season (Lorentz *et al.* 2005). For the pea crop, no data were found in the literature on harvest times.

Another factor that can cause variability in production is cultivation at different times, which can reduce or increase the number of harvests carried out on plants and which has already been seen in different cultures. In *Cucurbita pepo*, the highest dry matter production of the plant and the highest growth rate were obtained when they were grown in the spring-summer season, due to the different environmental conditions (Strassburger *et al.* 2011). While Lúcio et al. (2008) also studying *Cucurbita pepo* found significant heterogeneous variance between the growing seasons and also between the harvests, due to the different environmental conditions in each growing season. In the culture of *Capsicum annuum*, heterogeneous variance of the fruit masses was also observed between the growing seasons and between the rows in each harvest performed due to adverse physiological and environmental conditions (Lúcio *et al.* 2003).

An alternative for estimating the production of pea pods is through the selection of characters that allow, both directly and indirectly, for identifying the increased production of pods and grains. A favorable methodology for that estimate is the adoption of bivariate and multivariate analysis techniques such as Pearson's correlation analysis, path analysis and canonical correlation.

Through Pearson's correlation analysis, it is possible to identify the strength of relationship between two variables. However, correlations do not present the exact importance of the direct and indirect effects of the explanatory characters on the main character, and may not be a real measure of cause and effect, as this correlation between two variables may be due to the effect of one or more different characters (Cruz *et al.* 2012). The use of path analysis allows the correlation coefficient to be split into direct and indirect effects of characters on a main outcome variable (Wright 1921; Cruz *et al.* 2012).

Although path analysis is important in the study of direct and indirect effects, it takes into account only a single dependent variable. When working with different groups of characters, an alternative is the use of canonical correlation techniques, which allows the evaluation of the interrelationships between two complexes determined by a random number of characters. That is, there are two sets of variables in which seeks the maximum correlation between both (Cruz *et al.* 2012).

Several studies using multivariate analyzes for multiple harvest crops have been developed, for example, *Capsicum annuum* L. (Moreira *et al.* 2013), *Carica papaya* L. (Ferreira *et al.* 2012), *Cucurbita pepo* (Boligon *et al.* 2010) and *Brassica oleracea* L. var. *acephala* DC

(Azevedo *et al.* 2016). However, no reports were found in the literature using multivariate analyzes for the cultivation of peas with different harvest times. Thus, this work aims to evaluate the cause-and-effect relationships among pea production variables and to verify if they follow the same trend between harvests and growing seasons.

2.3 MATERIAL AND METHODS

Uniformity tests were conducted in the field in 2016, 2017 and 2018 in different scenarios. The experimental area was at the Department of Phytotechnics at the Federal University of Santa Maria - UFSM (S: 29 ° 42 '23' '; W: 53 ° 43' 15 " and 95 meters above sea level) in the municipality of Santa Maria - RS, where, according to the Köppen classification, the region's climate is of the Cfa type - rainy temperate, with rains well distributed throughout the year and subtropical from the thermal point of view (Alvares *et al.* 2013).

The soil of the experimental area is classified as Alfisols (Soil Survey Staff, 1999). Soil preparation of the experimental area was carried out with the rotary hoe, and basic fertilization was carried out according to the soil analysis, following the technical recommendations of the culture (ROLAS 2004).

The four uniformity tests were performed on a construction bed without the use of irrigation. The cultivar used was pea grain 40 and the tests were carried out in three growing seasons: Season 1 (05/03/2016), Season 2 (05/16/2017 - Tests 1 and 2) and Season 3 (06/04/2018). For Seasons 1 and 2, beds with two sowing lines were used, using the spacing of 0.45m between plants and 0.80m between rows, with each row being composed of 30 pits, containing four plants per pit, and each pit was considered a basic unit (UB). For Season 3, ridges with a row were used, using a spacing of 0.45m between plants and 0.80m between ridges, with each row consisting of 30 pits, containing four to five plants per pit where each pit was also considered a UB.

Pods were harvested in all UBs when they were light green in color. After being collected, they were packed in identified plastic bags and sent to the laboratory for counting and weighing on a digital scale. Five UB of each row were randomly chosen to measure the pod mass (MP, g), pod length (PL, cm), the number of grains per pod (NG, un.) and the mass of grains per pod (MG, g).

Data Analysis

The relationships between pairs of variables were estimated by Pearson's linear correlations and, subsequently, the direct and indirect effects were unfolded by path analysis, where the grain mass variable (MG) was the main dependent variable and the mass variables pods (MP), pod length (PL), number of grains (NG) were independent variables.

Before the path analysis, a multicollinearity diagnosis was made between the explanatory variables (MP, PL and NG) by analyzing the condition number $NC = \frac{\lambda \max}{\lambda \min}$, where $\lambda \max$ is the highest eigenvalue of the correlation matrix and the $\lambda \min$ is the smallest eigenvalue of the correlation matrix. The variance inflation factor was also calculated $VIF = \frac{1}{1 - R_j^2}$, where R_j^2 is the coefficient of determination. When NC<100, multicollinearity is considered weak, presenting no problems for the analysis, if the 100≤NC≤1000, multicollinearity is considered strong and if NC≥1000, it is considered severe (Montgomery and Peck 1981). The VIF needs to be less than 10 to not have serious problems with data analysis.

After the diagnosis of multicollinearity, the path coefficients were calculated using the methodology proposed by (Cruz *et al.* 2012): $Y = P_{o1}X_1 + P_{o2}X_2 + \ldots + P_{on} + X_n + P_u$, where Y is the coefficient of the dependent variable; P_o is the coefficient of direct effect; X is the explanatory independent variable; P_u it is the residual effect and the standardization variable.

The relationships between the groups of pod variables (Group I) and grain variables (Group II) were identified by the analysis of canonical correlations expressed by:

$r_1 = \frac{C\hat{o}v(X_1,Y_1)}{\sqrt{\hat{V}(X_1).\hat{V}(Y_1)}}$, where $C\hat{o}v(X_1,Y_1) = a'S_{12}b$, $\hat{V}(X_1) = a'S_{11}a$ and $\hat{V}(Y_1) = b'S_{22}b$, S_{11}= pxp matrix of covariance between characters in group I, S_{22}= qxq matrix of covariance between group II characters S_{12}= pxq matrix of covariance between characters in group I and II (Cruz *et al.* 2012). For group I the variables were pod mass (MP) and pod length (PL), and for group II the variables were grain mass (MG) and the number of grains (NG). For each group, the diagnosis of multicollinearity was made by VIF and NC.

Statistical analyses were performed at 5% significance with the aid of biotools packages (Silva *et al.* 2017) and Yacca (Butts 2018) in the R program (R Core Team 2019).

2.4 RESULTS

The temperature ranged from 33.2 °C to 0 °C for Season 1 (2016) (Figure 1a), from 35.4 to -1.2 °C in Season 2 (Figure 1c) and from 35.4 °C to -1 °C for Season 3 (2018) (Figure 1e). The total precipitation during the crop cycles was 345.2 mm, 654.0 mm and 496.5 mm for Season 1, Season 2 and Season 3, respectively (Figure 1 a, c and e). Regarding insolation, little variation was observed between the growing seasons, with a total in the crop cycle of 630.2 W / m² for Season 1, 659.9 W / m² for Season 2, and 574.6 W / m² for Season 3 (Figure 1 b, d and f). The mean relative humidity for the different seasons was 83.44%, 80.52% and 86.59%, for Seasons 1, 2 and 3, respectively (Figure 1 b, d and f).

The multicollinearity performed in the correlation matrix of the explanatory variables, by condition number (NC) and variance inflation factor (VIF), were low in all growing seasons. The determination coefficients ranged from 0.54 to 0.89 for different harvests at different times of crop cultivation.

The variables pod mass (MP) and number of grains (NG) showed the highest correlations and direct effect with the main dependent variable mass of grains (MG) in the first growing season. The variable pod length (PL) showed a low correlation and a negligible direct effect on all harvests. PL had an indirect effect via MP at harvest 1 and 2 and an indirect effect via NG at harvest 3 (Table 1).

For Season 2 - Tests 1, a high correlation was found for all variables with MG (Table 2). For the variable MP, there was a greater direct effect on MG in all harvests. For the variable PL, the direct effect was negligible, with an indirect effect via MP in harvest 1 and 2 and an indirect effect via NG in harvest 3. The NG variable had a high direct effect on the MG variable in harvests 1 and 3, but in harvest 2 the effect was indirect via MP.

For Season 2 – Tests 2, the highest correlations were observed for the variables MP and NG in all harvests (Table 3). The MP had a direct effect on MG in harvests 2 and 3, while in harvest 1 it had a low direct effect and an indirect effect via NG on MG. For the variable PL, a direct low and negative effect on MG was observed in all harvests, with an indirect effect via NG in harvest 1, and an indirect effect via PV in harvest 2 and 3. For the variable NG, a high direct effect on MG was observed only at harvest 1, while at harvest 2 and 3, an indirect effect was observed on MG via MP.

For Season 3, the greatest correlations with MG were observed for MP, in addition to a high direct effect, representing almost the entire value of the correlation, in all harvests, indicating the true cause and effect relationship (Table 4). For the variable PL as in Season 2, the direct effect on MG was low and negative, so the indirect effects were responsible for the low correlations in all harvests, presenting an indirect effect via MP. For the NG variable, the direct effects on MG were low, with an indirect effect via MP.

The canonical correlations between the characters of pods and grains for three harvests in Season 1 showed the first pair of significant canonical correlations. This result shows that these groups are dependent and that they can be used to study the characters of these groups. For harvest 1, the first canonical pair showed a correlation of r = 0.83, where the variable MP had a high and negative canonical load, while the same trend is observed in the grain characters, indicating that the pod mass interferes in grain production pea seeds (Table 5). In harvest 2, the canonical correlation was 0.76 and both groups showed negative correlations, in the same way as in harvest 1. There is a high negative correlation between the mass of pods with the number and the mass of grains, indicating the relationship between the groups evaluated. Finally, for harvest 3, in the same way as in harvest 1 and 2, the canonical loads showed high and negative magnitudes, indicating that the pod mass interferes with the production of pea grains (Table 5).

For Season 2– Tests 1, the three harvests performed showed the same trend, all of them showed a high canonical correlation for the first canonical pair (0.82, 0.92 and 0.86 respectively). This result indicates that these groups are dependent and that they can be used to study the characters (Table 6).

For Season 2– Tests 2 of cultivation, the three harvests analyzed showed the same trend, as in Season 1 and 2 – Tests 1. The canonical correlations for the first canonical pairs in the three harvests were 0.60, 0.85 and 0.84 respectively. The high and negative canonical loads in both pea pod and grain groups reveal the dependence of the groups, and they can be used in the selection of characters (Table 7).

For Season 3, evaluating the three harvests performed, the first pairs of significant canonical correlation (0.90, 0.82 and 0.78 respectively). Loads of the canonical pairs within the groups, in the first pair, were negative and high, confirming the results found for Seasons 1and 2 (Test 1 and 2) (Table 8).

2.5 DISCUSSION

Environmental factors such as radiation, humidity, temperature, and irradiation can interfere with the productivity of the pea crop. Temperature is one of the main factors, negatively affecting grain yield (Roro *et al.* 2016). Temperature is linked to the photosynthetic process of plants and can affect the rate of metabolic reactions, regulating plant growth and development. Increasing temperatures also induce an increase in the rate of photosynthesis and a decrease under very high temperatures (Monteiro 2009). This condition was verified by Zhang et al. (2016) showing that very low temperatures provided a decrease in the yield of the pea crop. Santín-Montanyá et al. (2014) found that the humidity and temperature varied during the growing seasons and affected the productivity of the pea crop. The same was verified by McMurray et al. (2011) who observed a decrease in production when there was little rainfall and maximum and medium high temperatures during the growing season.

Air temperature is linked to the various metabolic processes of plants. When they are subjected to low temperatures, water absorption by the roots is reduced, and leaf respiration, transpiration, stomatal opening and closing, availability and absorption of nutrients are also affected. When plants are subjected to warmer environments, they limit the efficiency of photosynthetic assimilation of carbon, because the progressive increase in temperature tilts the balance away from photosynthesis and towards photorespiration (Taiz *et al.* 2017).

Another important factor for the increase in pea production is the availability of water for the crop, which even with an osmotic adjustment when subjected to water deficit, is not enough for the growth of the plant, as it is important only in maintaining positive rates of photosynthesis, performing only energy supply to maintain the translocation and transfer of carbon and nitrogen from the leaves, stem and root to the developing seeds (Leport *et al.* 1998). As in the present study, irrigation was not carried out, the crop is dependent on rainwater, a fact that may have influenced the crop's low productivity, in addition to the other factors already mentioned. Netto et al. (1997) reported that when pea plants suffer intense and prolonged water stress, a reduction in crop productivity occurs.

With regards to the variation between harvests within each season, it may be related to the translocation of solutes from the source to the drain, since the measure in which the first harvest was taken by removing the pods, which are considered drains, the photoassimilates were redistributed to other drains such as flowers and new pods, even so in the present work, no increase in production. According to Taiz et al. (2017) the allocation and partition processes in the plant must be coordinated so that the increased transport to edible tissues does not happen at the expense of the essential processes and structures for the plant, and there must be a balance between the maintenance and growth processes of the plant so that have an increase in productivity.

The variables pod mass and number of grains showed the highest correlations, as well as greater direct and indirect effects with the mass of grains in all growing seasons. These results indicate that these variables can be used for the selection of more productive plants. The same was observed by Correa et al. (2012) working with the culture of *Vigna unguiculata* L. Walp, where they found a high and positive correlation with the weight of five pods and number of grains of five pods with grain yield. In a study with *Brassica napus*, a positive correlation was found between the number of silicas per plant and the higher number of grains per plant with grain productivity (Krüger *et al.* 2011). For peas, in the present study, even with the variability of environmental conditions between one harvest and another and between growing seasons, the linear relationships between variables followed the same trend between harvests and harvest times, with little variation between seasons, variations that can be attributed to differences in the environment from one seasons to another.

2.6 CONCLUSION

Pea production showed the same trend in the relationships between variables, in different harvests and growing seasons, suffering interference from environmental conditions.

The variables pod mass and number of grains are the variables with the highest cause and effect relationships on the mass of grains and can be used for the indirect selection of more productive plants.

Plants with a lower pod mass provide pods with a lower number of grains and less mass of grains according to the canonical correlation.

2.7 ACKNOWLEDGEMENTS

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2.8 DECLARATION OF CONFLICT OF INTEREST

The authors declare no conflict of interest. The founding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

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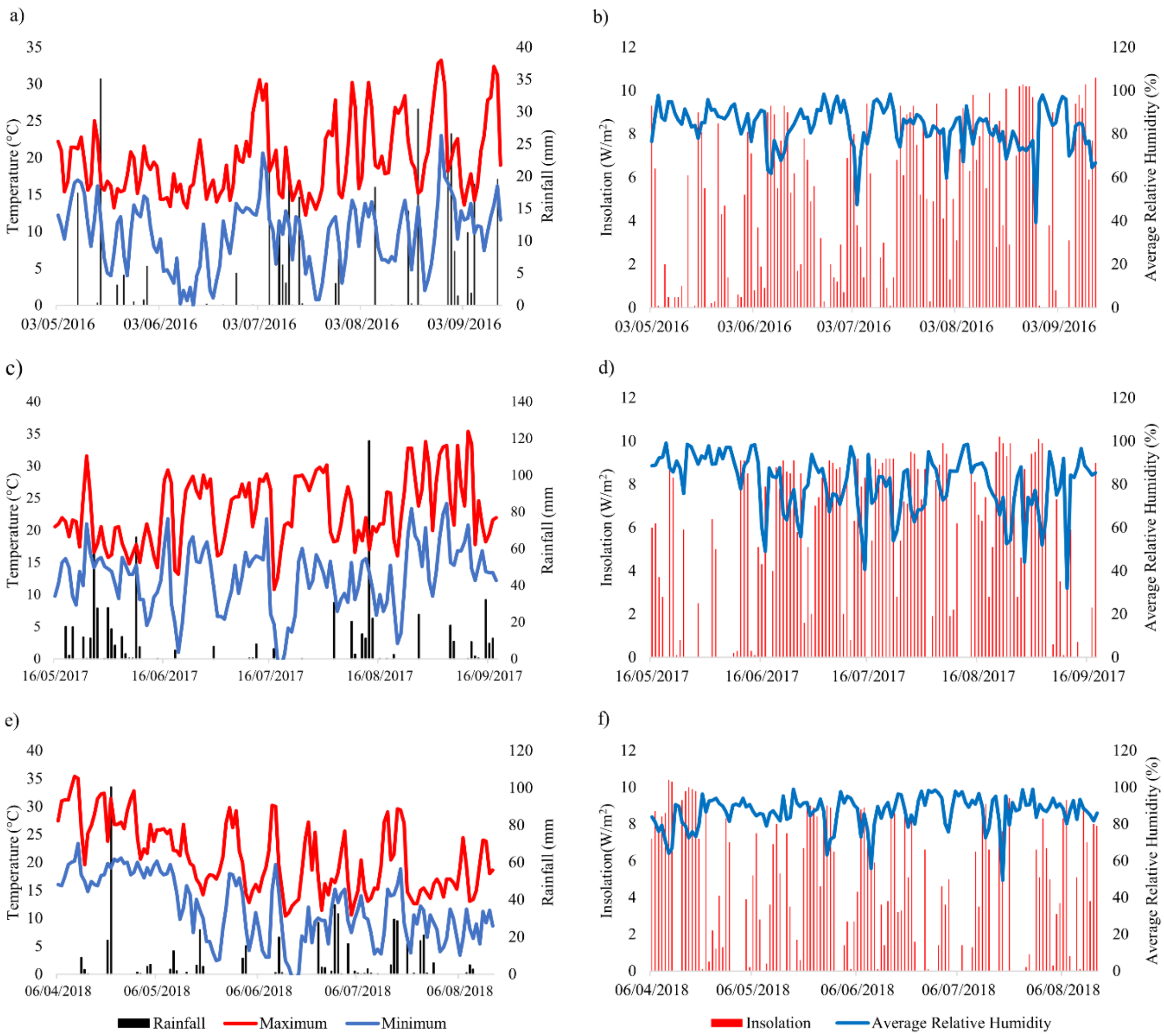

Fig.1 Values of precipitation, maximum and minimum temperature, insolation and average relative humidity for the years 2016, 2017 and 2018. (a) Maximum, minimum temperature and precipitation for season 1, (b) Insolation and relative humidity for the season 1, (c) Maximum, minimum temperature and precipitation for season 2, (d) Insolation and relative humidity for season 2, (e) Maximum, minimum temperature and precipitation for season 3, (f) Insolation and relative humidity for season 3.

Table 1: Pearson's linear correlations (r) and path analysis between the main dependent variable [direct effect (diagonal)] grain mass (MG) and the explanatory (indirect effects) pod mass (MP), pod length (PL), number of pea grains (NG) cultivated in 2016 (Season 1).

	Season 1											
	Harvest 1				Harvest 2				Harvest 3			
	MP	PL	NG	r	MP	PL	NG	r	MP	PL	NG	r
MP	**0.72**	-0.04	0.10	0.77**	**0.47**	-0.02	0.28	0.73**	**0.41**	-0.03	0.28	0.65**
PL	0.28	**-0.11**	0.05	0.22**	0.23	**-0.05**	0.21	0.39**	0.18	**-0.07**	0.23	0.34**
NG	0.51	-0.04	**0.14**	0.42**	0.3	-0.02	**0.44**	0.72**	0.19	-0.03	**0.61**	0.77**
R^2	0.62				0.65				0.71			
Residual	0.62				0.59				0.54			
VIF[1]	2.06	1.20	2.03		1.85	1.40	1.82		1.41	1.31	1.34	
CN[2]	6.75				5.87				3.52			

[1]VIF: Variance inflation factor; [2]CN: Condition number. ** Significant at 1% probability of error.

Table 2: Pearson's linear correlations (r) and path analysis between the main dependent variable [direct effect (diagonal)] and the explanatory (indirect effects) pod mass (MP), pod length (PL), number of pea grains (NG) cultivated in 2017 (Season 2 - Tests 1).

Season 2 - Tests 1												
	Harvest 1				Harvest 2				Harvest 3			
	MP	PL	NG	r	MP	PL	NG	r	MP	PL	NG	r
MP	**0.45**	0.003	0.34	0.80**	**0.7**	0.03	0.18	0.92**	**0.45**	-0.02	0.43	0.86**
PL	0.35	**0.004**	0.29	0.65**	0.41	**0.05**	0.13	0.6**	0.31	**-0.04**	0.34	0.62**
NG	0.34	0.002	**0.45**	0.80**	0.47	0.02	**0.27**	0.77**	0.36	-0.02	**0.55**	0.88**
R^2	0.73				0.89				0.85			
Residual	0.51				0.34				0.39			
VIF[1]	3.41	2.54	2.38		2.16	1.56	1.90		3.31	2.02	2.76	
[2]CN	12.47				6.97				12.36			

[1]VIF: Variance inflation factor; [2]CN: Condition number. ** Significant at 1% probability of error.

Table 3: Pearson's linear correlations (r) and path analysis between the main dependent variable [direct effect (diagonal)] grain mass (MG) and the explanatory (indirect effects) pod mass (MP), pod length (PL), number of pea grains (NG) cultivated in 2017 (Season 2 - Tests 2).

	Season 2 - Tests 2											
	Harvest 1				Harvest 2				Harvest 3			
	MP	PL	NG	r	MP	PL	NG	r	MP	PL	NG	r
MP	**0.29**	-0.01	0.31	0.59**	**0.59**	-1E-04	0.25	0.84**	**0.66**	-0.07	0.25	0.84**
PL	0.22	**-0.02**	0.28	0.48**	0.38	**-2E-04**	0.15	0.53**	0.44	**-0.11**	0.2	0.53**
NG	0.15	-0.009	**0.60**	0.74**	0.43	-7E-05	**0.34**	0.78**	0.43	-0.06	**0.38**	0.75**
R^2	0.60				0.77				0.78			
Residual	0.63				0.48				0.47			
VIF[1]	2.49	2.35	1.40		3,00	1.72	2.16		2.34	1.9	1.8	
[2]CN	8.84				10.36				7.69			

[1]VIF: Variance inflation factor; [2]CN: Condition number. ** Significant at 1% probability of error.

Table 4: Pearson's linear correlations (r) and path analysis between the main dependent variable [direct effect (diagonal)] grain mass (MG) and the explanatory (indirect effects) pod mass (MP), pod length (PL), number of pea grains (NG) cultivated in 2018 (Season 3).

	Season 3											
	Harvest 1				Harvest 2				Harvest 3			
	MP	PL	NG	r	MP	PL	NG	r	MP	PL	NG	r
MP	**0.87**	-0.18	0.19	0.88**	**0.88**	-0.11	0.01	0.78**	**0.69**	-0.29	0.25	0.65**
PL	0.63	**-0.25**	0.13	0.51**	0.6	**-0.16**	0.009	0.45**	0.51	**-0.4**	0.18	0.29**
NG	0.65	-0.13	**0.26**	0.78**	0.48	-0.08	**0.02**	0.42**	0.50	-0.21	**0.34**	0.64**
R^2	0.83				0.63				0.54			
Residual	0.41				0.61				0.67			
VIF[1]	3.52	2.12	2.27		2.06	1.97	1.49		3.49	2.23	2.16	
CN[2]	12.63				6.80				12.5			

[1]VIF: Variance inflation factor; [2]CN: Condition number. ** Significant at 1% probability of error.

Table 5: Correlations and canonical cross loads estimated between pod variables Group I: pod mass, pod length, and grain variables Group II: number of grains and grains for peas grown at season 1.

	Loads of canonical pairs					
	Harvest 1		Harvest 2		Harvest 3	
	1º	2º	1º	2º	1º	2º
Characters	Variable pods					
Pod mass	-0.83	-0.04	-0.75	0.03	-0.66	0.01
Pod length	-0.31	-0.20	-0.45	-0.17	-0.32	-0.22
	Grain variables					
Number of grains	-0.70	-0.11	-0.66	-0.10	-0.47	-0.18
Grain Mass	-0.78	0.08	-0.73	0.05	-0.66	-0.02
Canonical correlation	0.83	0.22	0.76	0.21	0.66	0.25
Degrees of freedom	4	1	4	1	4	1
p value	$2.2x10^{-16}$	$6.1x10^{-8}$	$2.2x10^{-16}$	$2.2x10^{-16}$	$2.2x10^{-16}$	$1.2x10^{-13}$

Table 6: Correlations and estimated canonical cross loads between pod variables Group I: pod mass, pod length, and grain variables Group II: number of grains and grains for peas grown in Season 2 - Test 1.

Loads of canonical pairs						
	Harvest 1		Harvest 2		Harvest 3	
	1º	2º	1º	2º	1º	2º
Characters	Variable pods					
Pod mass	-0.82	0.008	-0.91	0.008	-0.86	0.007
Pod length	-0.68	-0.05	-0.59	-0.1	-0.63	-0.1
	Grain variables					
Number of grains	-0.76	-0.03	-0.68	-0.08	-0.8	-0.06
Grain Mass	-0.80	0.02	-0.92	-0.006	-0.86	0.01
Canonical correlation	0.82	0.09	0.92	0.11	0.86	0.15
Degrees of freedom	4	1	4	1	4	1
p value	$2x10^{-16}$	0.03	$2x10^{-16}$	0.06	$2x10^{-16}$	0.02

Table 7: Correlations and canonical cross loads estimated between pod variables Group I: pod mass, pod length, and grain variables Group II: number of grains and grains for peas grown in Season 2 - Test 2.

	Loads of canonical pairs					
	Harvest 1		Harvest 2		Harvest 3	
	1º	2º	1º	2º	1º	2º
Characters			Variable pods			
Pod mass	-0.60	0.01	-0.85	0.001	-0.84	-0.005
Pod length	-0.51	-0.06	-0.53	0.04	-0.55	-0.18
			Grain variables			
Number of grains	-0.53	-0.05	-0.73	-0.03	-0.65	-0.15
Grain Mass	-0.59	0.02	-0.84	0.007	-0.84	0.009
Canonical correlation	0.60	0.10	0.85	0.05	0.84	0.23
Degrees of freedom	4	1	4	1	4	1
p value	1.17×10^{-13}	0.21	2×10^{-16}	0.54	2.2×10^{-16}	0.003

Table 8: Correlations and canonical cross loads estimated between pod variables Group I: pod mass, pod length, and grain variables Group II: number of grains and mass of grains for peas grown in Season 3.

	Loads of canonical pairs					
	Harvest 1		Harvest 2		Harvest 3	
	1º	2º	1º	2º	1º	2º
Characters	Variable pods					
Pod mass	-0.88	-0.03	-0.82	-0.01	0.76	-0.06
Pod length	-0.52	-0.15	-0.53	-0.22	0.46	-0.24
	Grain variables					
Number of grains	-0.74	-0.10	-0.53	-0.22	0.72	-0.11
Grain Mass	-0.90	0.01	-0.79	0.08	0.68	0.14
Canonical correlation	0.90	0.18	0.82	0.28	0.78	0.3
Degrees of freedom	4	1	4	1	4	1
p value	$2x10^{-16}$	0.01	$2.2x10^{-16}$	0.009	$2.2x10^{-16}$	0.0002

3 ARTIGO 2 – EXPERIMENTAL PLAN FOR TESTS WITH PEA

Submetido para o periódico: Agronomy Journal

Situação: Aceito

Experimental Plan For Tests With Pea

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3.1 ABSTRACT

Correct experimental planning is important to obtain more reliable data with high experimental precision. In this way, the results obtained and the technical recommendations generated are more reliable and representative. Thus, the objective of this work is to estimate the plot and sample sizes and the number of repetitions for the variables number of pods per plant and mass of pods per plant for pea cultivation. Uniformity tests were carried in the years 2016, 2017 and 2018 in the experimental area of the Crop Science Department at Federal University of Santa Maria - UFSM, Brazil. The cultivar used was Pea Grain 40 which has an indeterminate growth habit, with a cycle of 75 to 90 days and a cylindrical pod. The plot size for evaluating the number of pods per plant and the mass of pods per plant for pea cultivation is eight and nine plants, respectively. The sample size for evaluating the number of pods per plant and the mass of pods per plant is eight plants in the direction of the line with a half-width of the 20% confidence interval of the mean. For the variables number of pods per plant and pod mass per pea plant 10 and 12 repetitions are required, respectively, to evaluate up to 20 treatments in a randomized block design and in the incomplete blocks design with up to 100 treatments for significant differences of 35% between treatment averages.

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3.2 INTRODUCTION

The pea (*Pisum sativum* L.) is an annual herbaceous legume, with cultivars classified as being of determined and indeterminate growth. Cultivars that show indeterminate growth are used for edible pods production whereas cultivars with determined growth are used for grain production (Filgueira, 2008).

Worldwide, in 2018, the production of dry pea occupied 7.88 million hectares of cultivated area with a production of 13.53 million tons; the largest producers are Europe (38.8%), North and South America (33.6%), Asia (20.5%), Africa (4.6%) and Oceania (2.5%). The production of green peas occupied 2.74 million hectares with a production of 21.2 million tons; the largest producers are Asia (8.5%), Europe (5%), Africa (3.2%), North and South America (3.1%) and Oceania (0.3%) (FAOSTAT, 2020). In Brazil, 2,813 tons of peas were produced in an area of 837 hectares, with the southeastern region of Brazil being the largest grain producer in the country (FAOSTAT, 2020; IBGE, 2020).

Due to the high nutritional importance of peas, scientific research is carried out, mainly related to their production and their expansion into new production regions. Correct experimental planning is important to obtain reliable data with high experimental precision. In this way, the results obtained and the technical recommendations generated are more reliable and representative. The use of many repetitions per treatment, adequate sample and plot sizes and an experimental design that provides control of plot variability are important to reduce experimental error and, consequently, to increase experimental precision. Furthermore, there are practical advantages in reducing the working time, labor and cost necessary to carry out the experiment.

At the time of experimental planning, one of the main problems is to determine the number of repetitions shape and the size of the plot necessary to identify significant differences between the treatment means in the local conditions of the experiment, with relation to the culture used and the variables measured to improve experimental accuracy (Silva, 2014). The size of the plot will depend on the experimental material, the number of treatments, the area, the cost and the labor available (Lúcio and Sari, 2017). Furthermore, plot size can vary according to the plant species to be cultivated, the size of the plant, the location of the experiment, the age of the plants, the evaluated characteristics, the number of plants used in the basic unit, the time of evaluation, the shape of the plot and the method used for its estimation (Silva, 2014).

The number of repetitions per treatment is important to estimate the experimental error and the average of each treatment and to evaluate more precisely each treatment (Storck et al., 2011; Lúcio and Sari, 2017). It is known that the greater the number of repetitions, the smaller the residual variance of the treatments and, consequently, the lower the estimate of the mean square of the error. This condition reduces the probability of the occurrence of type II error at the time of statistical analysis of the experimental data. Thus, statistical conclusions come to have greater experimental precision.

Another common (and one often performed without proper experimental planning) is the use of sampling in the plots. This practice causes a source of experimental variation that is defined as a sampling error, which corresponds to the variability within the sample. Often this variability is neglected in the analysis of variance and ends up inflating the mean square of the error (Lúcio and Sari, 2017). One way to reduce the sampling error is to use more accurate measuring instruments and a sample sized to the desired precision (Lúcio et al., 2003).

Several works have already been carried out in different cultures to estimate the plot size (Oliveira and Estefanel, 1995; Lorentz and Lúcio, 2009; Lúcio et al., 2012; Santos et al., 2012; Brum et al., 2015), the number of repetitions (Lúcio et al., 2004; Cargnelutti Filho and Ribeiro, 2010; Cargnelutti Filho et al., 2015; Torres et al., 2015) and the sample size (Haesbaert et al., 2011; Silva et al., 2011; Cargnelutti Filho et al., 2012; Lúcio et al., 2012; Toebe et al., 2014). For forage pea the plot size and number of repetitions for the green mass have already been determined (Cargnelutti Filho et al., 2015). Among published studies peas intended for grain production, only a work by Nonnecke (1960) was found that studied the influence of different sizes and forms of plot and block for the total production of peas. However, no studies were found with estimates for the productive variables of the crop.

Thus, the objective of this work is to estimate plot and sample sizes and the number of repetitions for the variables number of pods per plant and mass of pods per plant for pea cultivation.

3.3 MATERIAL AND METHODS

Uniformity tests were carried out in the field and on the same plot of land, in the years 2016, 2017 and 2018 in the experimental area of the Crop Science Department at Federal University of Santa Maria – UFSM (29°42′23″ S, 53°43′15″ W; 95 m asl) in the municipality of Santa Maria - RS, Brazil, where according to the Köppen classification the region's climate is of the Cfa type - rainy temperate with rains well distributed throughout the year and subtropical temperatures(Alvares et al., 2013).

The soil of the experimental area is classified as Alfisols (Soil Survey Staff, 1999). Soil preparation of the experimental area was carried out with the rotary hoe, and basic fertilization was carried out according to the soil analysis following the technical recommendations of the crop (ROLAS, 2004).

The three uniformity tests were performed on beds and ridges without the use of irrigation. In the first and second years (2016 and 2017), in each uniformity test, beds were used with two rows of sowing, with spacing of 0.45 m between plants and 0.80 m between rows. Each row consisted of 30 pits containing four plants per hole, and each pit was considered a basic unit (BU), totaling eight cultivation rows for the 2016 trial and 11 cultivation rows for the 2017 trial. For the year 2018 uniformity trial, ridges had one row, totaling five rows of cultivation, with spacing of 0.45 m between plants and 0.80 m between ridges, each row consisted of 30 pits containing four to five plants per pit,and each pit was a BU. There Were a total of 240, 330 and 150 BUs for the years 2016, 2017 and 2018 respectively. The cultivar used was Pea Grain 40 which has an indeterminate growth habit, with a cycle of 75 to 90 days and a cylindrical pod. Sowing was carried out on 3 May 2016, 16 May 2017, and 6 Apr. 2018. For the analysis, the average number of pods and pod mass of each pit was per plant.

Pods were harvested in all BUs when they were light green. Harvested pods were packed in identified plastic bags and sent to the laboratory for counting and weighing on a digital scale. In each BU and in each harvest, we measured pods mass per plant (MPP, in g) and the number of pods per plant (NPP,). Therefore, three harvests were carried out on each plot in all growing seasons. The harvests (H) were analyzed individually and grouped in all tests (H1 + H2) and (H1 + H2 + H3).

To test the homogeneity of variances between cultivation rows and for each year, Bartlett's test was performed (Steel et al., 1997) at the 5% probability of error,and the sample sizes were estimated by the expression: $n = \frac{t^2_{\alpha/2}(CV\%)^2}{(D\%)^2}$, where *n* is the sample size, $t^2_{\alpha/2}$ is the value of Student's t-table with *n*-1 degrees of freedom at 5% probability of error, CV% is the coefficient of variation of each variable, calculated by the expression: $CV\% = \frac{100\times\sqrt{s^2}}{\bar{X}}$, where s^2 is the sample variance, $\bar{X}$ is the mean of each variable and *D*% is the half-width of the mean confidence interval (*D*% = 5, 10, 15, 20%). Correction for the finite population was still carried out, according to the Cochran recommendation (1997), using the expression: $nc = \frac{n}{1+\frac{n}{N}}$ where *nc* is the corrected sample size, *N* is the population size and *n* is the sample size for the infinite population.

To estimate the plot size, the maximum curvature method of the variation coefficient proposed by Paranaiba; Ferreira; Morais (2009) was used, according the following expression: $\hat{X}_0 = \frac{10\sqrt[3]{2(1-\hat{p}^2)s^2\bar{X}}}{\bar{X}}$, where $\hat{X}_0$ is the appropriate plot size, s^2 is the variance in the crop row, $\bar{X}$ is the average of BUs in the cultivation row, $\hat{\rho}$ is the first order spatial auto-correlation estimated by the expression: $\rho = \frac{\sum_{i=1}^{rc}(\hat{\varepsilon}_1 - \bar{\varepsilon})(\hat{\varepsilon}_{i-1} - \bar{\varepsilon})}{\sum_{i=1}^{rc}(\hat{\varepsilon}_1 - \bar{\varepsilon})^2}$, Where $\hat{\varepsilon}_1$ and $\hat{\varepsilon}_{i-1}$ are the model errors containing only the intercept in BU (*i* and *i* -1) respectively.

To estimate the number of replications the method proposed by Steel et al. (1997) was used, where the minimum significant difference (*d*) of the Tukey test was used, expressed as a percentage of the test mean: $\mathrm{d} = \left(\mathrm{q}_{\alpha(\mathrm{i;GLE})}\sqrt{\mathrm{QME/r}}\right)/\mathrm{m}\times100$, where $\mathrm{q}_{\alpha(\mathrm{i;GLE})}$ is the critical value of the Tukey test at α level of error probability (α = 0.05), *i* is the number of treatments, GLE is the number of degrees of freedom of error, that is, (*i*-1) (*r*-1) for the randomized block design, QME is the mean square of the error, *r* is the number of repetitions and *m* is the mean of the experiment. Thus, replacing the expression of the experimental variation coefficient we have: $(\mathrm{CV}=\sqrt{\mathrm{QME}}/\mathrm{m}\times100)$. In percentage, in the expression for the calculation of *d* and isolating *r*, we have $\mathrm{r} = (\mathrm{q}_{\alpha(\mathrm{i;GLE})}\mathrm{CV/d})^2$.

In this work, the CV was expressed as a percentage and corresponds to the $\mathrm{CV}_{\mathrm{Xo}}$, which is the expected CV for the experiment with the plot size (Xo) determined. With the highest coefficient of variation of the plot size ($\mathrm{CV}_{\mathrm{Xo}}$), the number of repetitions (*r*) was determined by the iterative process until convergence for experiments in randomized block design, in scenarios formed by the combinations of *i* (*i* = 2, 3, 4, ..., 20) and *d* (*d* = 5%, 10%, 15%, ..., 50%).

Additionally, the number of repetitions was estimated for incomplete blocks with more than 20 treatments, following the number of treatments in the Tukey table up to 100 treatments.

The same formula was used $d = \left(q_{\alpha(i;GLE)}\sqrt{QME/r}\right)/m\times100$, where $q_{\alpha(i;GLE)}$ is the critical value of the Tukey test at α level of error probability (α = 0.05), *i* is the number of treatments, GLE is the number of degrees of freedom of the error (*n*-*i*-*r* + 1) for the incomplete block design, QME is the average square of the error, *r* is the number of repetitions and m is the average of the experiment.

Statistical analyzes were performed using Microsoft Office Excel® and the R program (R Core Team 2019), with the aid of metan packages (Olivoto and Lúcio, 2020) and tidyverse (Wickham et al., 2019).

3.4 RESULTS

3.4.1. Experimental variability

The results of Bartlett's tests carried out between the variances of the crop rows in each harvest showed that in the 2016 and 2017 crops the variances were heterogeneous for the two measured variables. In 2018, the was no statistical evidence that variances between the rows of cultivation in each harvest were heterogeneous, except in harvest 3 for both variables measured (Tables 1 and Supplemental Table S1, S2). Thus the most appropriate is the use of blocks towards the rows to ensure control of this source of heterogeneity existing in the first two years of testing. This fact shows that the randomized blocks should be the experimental design adopted, because the use of a completely randomized design demands total homogeneity among experimental plots (Steel *et al*., 1997), and this was not observed when using the Barlett’s test (Table 1 and Supplemental Table S1, S2). Thus, according to Lúcio & Sari, (2017), each block/replicate should be composed of one cultivation row.

3.4.2. Plot size

When estimating the plot size for the two variables studied, it was found that in 2017 the seventh row of cultivation (F7) had an anomalous characteristic, that interfered in the estimation of the sample size and the number of repetitions (data not shown). Thus, it was decided to remove this row of cultivation and perform the analysis again to estimate the plot size and later the sample size and number of repetitions.

Plot size varied between the harvests, between the rows of crops and between the years of cultivation for the two variables analyzed (Table 1 and Supplemental Table S1, S2). For the variable NPP, the plot size decreases as the accumulation of harvests took place (H1 + H2 + H3) (Table 1 and Supplemental Table S1). The CV varied from 3.55% to 29.23% between the three years of cultivation. For 2016, in the accumulated harvests, the largest plot size was eight plants with a coefficient of variation of 18.07% while in 2017 the plot size was seven plants with a CV of 15.77% showing the highest values in the central rows. In 2018, the plot size was five plants with a CV of 11.74%. Thus, grouped crops should be used to measure the pea NPP, and plots should be composed of eight plants per cultivation row.

Table 1. Smallest and largest plot size (Xo, in plants) and their coefficients of variation in plot size in parentheses (CV_{Xo}, in%) of the cultivation rows in each year, between individual crops and grouped for the number of pods per plant (NPP) and pod weight per plant (MPP) and the p-value of Bartlett's test between rows in each crop over three years of cultivation for pea cultivation.

		Harvests				
	Years	H1	H2	H3	H1+H2	H1+H2+H3
NPP	2016	7(16.5) 10(22.1)	4(9.1) 10(22.6)	5(11.9) 9(16.7)	3(7.4) 10(21.4)	3(7.5) 8(18.07)
	p-value[1]	<0.001	<0.001	<0.001	<0.001	<0.001
	2017	3(7.0) 10(22.4)	3(6.7) 13(29.9)	4(9.7) 8(17.1)	2(3.5) 7(16.4)	2(5.0) 7(14.9)
	p-value[1]	<0.001	<0.001	0.0225	<0.001	<0.001
	2018	5(11.7) 11(24.5)	8(18.1) 11(24.2)	5(11.5) 8(17.2)	5(11.8) 8(18.5)	4(9.5) 5(11.7)
	p-value[1]	0.0599	0.2300	0.0187	0.813	0.931
MPP	2016	8(17.6) 11(25.5)	4(9.5) 10(22.7)	6(13.4) 10(22.7)	4(8.0) 10(21.9)	4(7.9) 9(19.7)

p-value[1]	<0.001	<0.001	<0.001	<0.001	<0.001
2017	3(6.8)	3(6.9)	4(9.4)	2(4.4)	2(5.11)
	9(20.5)	13(28.4)	10(21.3)	8(18.6)	8(18.6)
p-value[1]	<0.001	<0.001	0.0201	<0.001	<0.001
2018	5(11.65)	9(21.0)	6(14.3)	5(12.1)	5(10.1)
	11(25.0)	11(24.2)	8(18.4)	9(19.5)	6(13.0)
p-value[1]	0.1530	0.0569	0.0049	0.872	0.889

[1]: *p-values* lower than 0.05 shows heterogeneous variances between rows of cultivation within each individual or grouped harvest.

For the MPP variable, the plot size also decreased as the accumulation of harvests took place. The CV varied from 4.42% to 28.44% between the growing seasons. In 2016 the largest plot size in the accumulated harvest (H1 + H2 + H3) was nine pea plants. In 2017, the largest plot sizes were also located in the central rows of the uniformity test, where the highest value was eight plants for evaluating the MPP variable. In 2018, the plot size for the accumulated harvest was six plants with a CV of 12.98%. Therefore, for the measurement of the MPP variable, the crops should be grouped, and each plots should be composed of nine plants per row (Table 1 and Supplemental Table S2).

3.4.3. Sample size

Sample sizes (in number of plants) in most rows were smaller for grouped harvests than for individual harvests in the different years of cultivation (Tables 2 and Supplemental Table S3, S4). For the variable NPP, the sample size varied from one to 13 plants regardless of the row, harvest and year of cultivation (Table 2 and Supplemental Table S3). For a half-width of the confidence interval (D%) equal to 5% of the average, the sample size for individual crops ranged from three to 13 plants between the different years of cultivation. For the accumulated harvests, the sample size varied from two to 10 plants.

For a half-width of the confidence interval (*D*%) equal to 20% of the average, the sample size for the variable NPP varied from two to 12 plants at different times for individual harvests.

For grouped harvests, the sample size varied from one to nine plants at different growing seasons.

Table 2. Smallest and largest sample size (in number of plants) of the cultivation rows in each individual harvest (H1, H2 and H3) and grouped (H1 + H2 and H1 + H2 + H3) for the number of pods per plant (NVP), pods mass per plant (MPP), and half-width of the mean confidence interval (*D*% = 5, 10, 15 and 20%), in three years of cultivation for pea cultivation.

		NPP			MPP		
Harvests	D%	2016	2017	2018	2016	2017	2018
H1	5	8-11	3-10	5-11	8-11	3-9	5-11
	10	8-11	3-10	5-11	8-11	3-9	5-11
	15	7-10	3-10	4-10	7-10	3-9	4-10
	20	7-10	2-9	4-10	7-10	2-8	4-10
H2	5	4-10	3-13	8-11	4-10	3-13	9-11
	10	4-10	3-13	8-11	4-10	3-13	9-11
	15	3-8	3-12	8-10	3-9	3-12	8-10
	20	3-9	3-12	7-10	3-9	2-12	8-10
H3	5	6-10	4-8	5-8	6-10	4-10	6-8
	10	6-10	4-8	5-8	6-10	4-10	6-8
	15	5-9	4-7	5-7	5-9	4-9	6-7
	20	5-9	3-7	4-7	5-9	4-9	5-7
H1+H2	5	4-10	2-7	5-8	4-10	2-8	5-9
	10	4-10	2-7	5-8	4-10	2-8	5-9
	15	3-9	1-7	5-7	3-9	2-8	5-8
	20	3-9	1-6	4-7	3-9	1-7	4-8
H1+H2+H3	5	4-9	2-7	4-5	4-9	2-8	4-6
	10	4-9	2-7	4-5	4-9	2-8	4-6
	15	3-8	2-7	4-5	3-8	2-8	4-5
	20	3-8	1-6	3-4	3-8	2-7	3-5

The sample size for measuring the pea MPP variable ranged from three to 13 plants for a half-width of the confidence interval (*D*%) equal to 5% of the average for individual harvests, while for the accumulated harvests the variation was from three to ten plants for the same confidence interval as the average (Table 2 and Supplemental Table S4). For *D*% equal to 20% of the average, the sample size varied from two to 12 plants for individual harvests, and from one to nine plants for accumulated harvests, regardless of the row and growing season.

3.4.4. Number of repetitions

3.4.4.1 Complete block design

The number of repetitions for the NPP and MPP variables was estimated from the largest plot size and its coefficient of variation for the grouped harvests. The number of repetitions for measuring the NPP variable in 2016 ranged between 3 (three treatments, *d* = 50%) and 484 (two treatments, *d* = 5%) (Table 3), whereas in 2017 the number of repetitions ranged between 2 (four treatments, *d* = 50%) and 369 (two treatments, *d* = 5%). In 2018, the number of repetitions was between 1 (it is recommended above 2) (three treatments, *d* = 50%) and 204 (two treatments, *d* = 5%) (Supplemental Table S5).

Table 3. Number of repetitions for experiments in the randomized block design, in scenarios formed by the combinations of "*i*" treatments (*i* = 2, 3, 4, ..., 20) and "*d*" minimum differences between means of treatments a be detected as significant at 5% probability, by the Tukey test, expressed as a percentage of the average of the experiment (*d* = 5, 10, 15, ..., 50%), for the variable number of pods per plant, from plot the largest size of plot (Xo = 8 plants) and coefficient of variation in plot size (CV_{Xo} = 18.1%) for growing peas in 2016.

	d %									
i	**5%**	**10%**	**15%**	**20%**	**25%**	**30%**	**35%**	**40%**	**45%**	**50%**
2	484	121	54	30	19	13	10	8	6	5
3	332	83	37	21	13	9	7	5	4	3
4	314	78	35	20	13	9	6	5	4	3
5	312	78	35	20	12	9	6	5	4	3
6	315	79	35	20	13	9	6	5	4	3
7	320	80	36	20	13	9	7	5	4	3
8	325	81	36	20	13	9	7	5	4	3
9	330	83	37	21	13	9	7	5	4	3
10	336	84	37	21	13	9	7	5	4	3
11	341	85	38	21	14	9	7	5	4	3
12	353	88	39	22	14	10	7	6	4	4
13	350	88	39	22	14	10	7	5	4	4
14	360	90	40	22	14	10	7	6	4	4
15	355	89	39	22	14	10	7	6	4	4
16	363	91	40	23	15	10	7	6	4	4
17	371	93	41	23	15	10	8	6	5	4
18	378	95	42	24	15	11	8	6	5	4
19	385	96	43	24	15	11	8	6	5	4
20	392	98	44	25	16	11	8	6	5	4

For the measurement of the MPP variable in 2016, the number of repetitions ranged between 4 (three treatments, *d* = 50%) and 575 (two treatments, *d* = 5%) (Table 4), whereas in

2017 it ranged between 3 (four treatments,*d* = 50%) and 513 (two treatments, *d* = 5%). In 2018, the number of repetitions was between 2 (two treatments, *d* = 50%) and 250 (two treatments, *d* = 5%) (Supplemental Table S6).

Table 4. Number of repetitions for experiments in the randomized block design, in scenarios formed by the combinations of "*i*" treatments (*i* = 2, 3, 4, ..., 20) and "*d*" minimum differences between means of treatments a be detected as significant at 5% probability, by the Tukey test, expressed as a percentage of the average of the experiment (*d* = 5, 10, 15, ..., 50%), for the variable mass of pods per plant, from plot the largest size of plot (Xo = 9 plants) and coefficient of variation in plot size (CV_{Xo} = 19.7%) for the pea crop for growing peas in 2016.

	d %									
i	**5%**	**10%**	**15%**	**20%**	**25%**	**30%**	**35%**	**40%**	**45%**	**50%**
2	575	144	64	36	23	16	12	9	7	6
3	394	98	44	25	16	11	8	6	5	4
4	372	93	41	23	15	10	8	6	5	4
5	371	93	41	23	15	10	8	6	5	4
6	374	93	42	23	15	10	8	6	5	4
7	380	95	42	24	15	11	8	6	5	4
8	386	97	43	24	15	11	8	6	5	4
9	392	98	44	25	16	11	8	6	5	4
10	399	100	44	25	16	11	8	6	5	4
11	405	101	45	25	16	11	8	6	5	4
12	419	105	47	26	17	12	9	7	5	4
13	416	104	46	26	17	12	8	7	5	4
14	427	107	47	27	17	12	9	7	5	4
15	421	105	47	26	17	12	9	7	5	4
16	431	108	48	27	17	12	9	7	5	4
17	441	110	49	28	18	12	9	7	5	4
18	449	112	50	28	18	12	9	7	6	4
19	457	114	51	29	18	13	9	7	6	5
20	466	116	52	29	19	13	10	7	6	5

3.4.4.1 Incomplete block design

The number of repetitions for the NPP and MPP variables for incomplete blocks was also estimated from the largest plot size and its coefficient of variation for the grouped harvests. The number of repetitions for the measurement of the NPP variable in 2016 ranged between 3 (three treatments, *d* = 50%) and 484 (two treatments, *d* = 5%) (Table 5), whereas in 2017 the number of repetitions fluctuated between 2 (four treatments, *d* = 50%) and 391 (100 treatments, *d* = 5%). In 2018, the number of repetitions was between 1 (three treatments, *d* = 50%) and 217 (100 treatments, *d* = 5%) (Supplemental Table S7).

Table 5. Number of repetitions for experiments in the design in incomplete blocks, in scenarios formed by the combinations of "*i*" treatments (*i* = 2, 3, 4, ..., 100) and "*d*" minimal differences between the means of the treatments to be detected as significant at 5% probability, by the Tukey test, expressed as a percentage of the average of the experiment (*d* = 5, 10, 15, ..., 50%), for the variable number of pods per plant, of the plot the largest plot size (Xo = 8 plants) and coefficient of variation in plot size (CVXo = 18.1%) for growing peas in 2016.

	d %									
i	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%
2	484	121	54	30	19	13	10	8	6	5
3	332	83	37	21	13	9	7	5	4	3
4	314	78	35	20	13	9	6	5	4	3
5	312	78	35	20	12	9	6	5	4	3
6	315	79	35	20	13	9	6	5	4	3
7	320	80	36	20	13	9	7	5	4	3
8	325	81	36	20	13	9	7	5	4	3
9	330	83	37	21	13	9	7	5	4	3
10	336	84	37	21	13	9	7	5	4	3
11	341	85	38	21	14	9	7	5	4	3
12	353	88	39	22	14	10	7	6	4	4
13	350	88	39	22	14	10	7	5	4	4
14	360	90	40	22	14	10	7	6	4	4
15	355	89	39	22	14	10	7	6	4	4
16	363	91	40	23	15	10	7	6	4	4
17	371	93	41	23	15	10	8	6	5	4
18	378	95	42	24	15	11	8	6	5	4
19	385	96	43	24	15	11	8	6	5	4
20	392	98	44	25	16	11	8	6	5	4
24	397	99	44	25	16	11	8	6	5	4
30	424	106	47	27	17	12	9	7	5	4
40	438	109	49	27	18	12	9	7	5	4
60	472	118	52	29	19	13	10	7	6	5
80	491	123	55	31	20	14	10	8	6	5
100	513	128	57	32	21	14	10	8	6	5

For the measurement of the MPP variable in 2016, the number of repetitions varied between 4 (three treatments, *d* = 50%) and 610 (100 treatments, *d* = 5%) (Table 6), whereas in 2017 it varied between 3 (four treatments, *d* = 50%)and 544 (100 treatments, *d* = 5%). In 2018, the number of repetitions was between 2 (two treatments, *d* = 50%) and 265 (100 treatments, *d* = 5%) (Supplemental Table S8).

The number of repetitions necessary to estimate the NVP and MVP in experiments in the randomized block design and experiments for incomplete blocks is the same, reducing only the number of treatments per block in the incomplete block design.

Table 6. Number of repetitions for experiments in the design in incomplete blocks, in scenarios formed by the combinations of "*i*" treatments (*i* = 2, 3, 4, ..., 100) and "*d*" minimum differences between means of treatments a be detected as significant at 5% probability, by the Tukey test, expressed as a percentage of the average of the experiment (*d* = 5, 10, 15, ..., 50%), for the variable mass of pods per plant, from plot the largest size of plot (Xo = 9 plants) and coefficient of variation in plot size (CVXo = 19.7%) for growing peas in 2016..

	d %									
i	**5%**	**10%**	**15%**	**20%**	**25%**	**30%**	**35%**	**40%**	**45%**	**50%**
2	575	144	64	36	23	16	12	9	7	6
3	394	98	44	25	16	11	8	6	5	4
4	372	93	41	23	15	10	8	6	5	4
5	371	93	41	23	15	10	8	6	5	4
6	374	93	42	23	15	10	8	6	5	4
7	380	95	42	24	15	11	8	6	5	4
8	386	97	43	24	15	11	8	6	5	4
9	392	98	44	25	16	11	8	6	5	4
10	399	100	44	25	16	11	8	6	5	4
11	405	101	45	25	16	11	8	6	5	4
12	419	105	47	26	17	12	9	7	5	4
13	416	104	46	26	17	12	8	7	5	4
14	427	107	47	27	17	12	9	7	5	4
15	421	105	47	26	17	12	9	7	5	4
16	431	108	48	27	17	12	9	7	5	4
17	441	110	49	28	18	12	9	7	5	4
18	449	112	50	28	18	12	9	7	6	4
19	457	114	51	29	18	13	9	7	6	5
20	466	116	52	29	19	13	10	7	6	5
24	471	118	52	29	19	13	10	7	6	5
30	504	126	56	31	20	14	10	8	6	5
40	520	130	58	32	21	14	11	8	6	5
60	560	140	62	35	22	16	11	9	7	6
80	583	146	65	36	23	16	12	9	7	6
100	610	152	68	38	24	17	12	10	8	6

3.5 DISCUSSION

3.5.1. Experimental variability

In vegetable crops, intensive management and high demand for labor are common, however, these factors make planning, conducting and analyzing data difficult. In addition, uneven maturation and variability of the experimental area is common and generates greater heterogeneities in the experiment. Often the experimental error is inflated due to problems in the design and implementation of the experiment. In these cases, the experiments have low precision, and the experimental results have little reliability (Lúcio and Sari, 2017).

Experimental planning must minimize natural variability within the experimental area, caused by differences in soil, variation between beds, and intensive labor that leads to heterogeneous plant management. If these factors are not controlled, experimental errors occur and it is not possible to conclude that the variability observed between treatments was not due to chance, increasing the type II error rate. The use of randomized block design tends to minimize these variations caused by the factors mentioned, leading to greater reliability of the results (Lúcio and Sari, 2017).

The heterogeneity of the variances between the rows of cultivation and harvest times may be related to the uneven growth and reproduction between plants, causing the early or late ripening of some fruits, due to physiological changes or environmental conditions (Lúcio et al., 2003). Heterogeneity has been observed in studies, as *Solanum melongena* L. (Krysczun et al., 2018), *Capsicum annuum* (Lorentz et al., 2005) and *Pisum sativum* (Nonnecke, 1960).

The coefficient of variation (CV) is widely used as a measure of the quality of the experiment and can be classified as low when less than 10%, medium when between 10 and 20%, high between 20 and 30% and very high when is greater than 30% (Pimentel-Gomes, 1990), being indicative of experimental precision. In the present study, the CV% oscillated between the low and high classes, however, the magnitudes of these coefficients are within the limits observed in different studies carried out with the pea culture. Furthermore, the accumulation of harvests provides a reduction in the estimates of the portion size of the variability between plants in the same crop segment because it decreases null values in the data set, which could be caused by uneven maturity or the presence of unharvested fruits (Krysczun et al., 2018). These results were verified by Nonnecke (1960), when studying the pea culture, indicating that the best way would be the use of the grouped samples in order to reduce the variation in each plot.

3.5.2. Plot Size

The most suitable plot sizes and shapes are those that provide less variation between plots in the same set (Lúcio and Sari, 2017). Therefore, the use of the largest portion size of the accumulated crops is the most suitable for estimating the NPP and MPP for the pea culture. The efficiency of the use of accumulated harvests has already been verified for several cultures such as *Lycopersicum esculentum* L. (Lúcio et al., 2010), *Solanum melongena* L. (Krysczun et al., 2018) and *Phaseolus vulgari*s L. (Santos et al., 2012).

When plot sizes have not yet been estimated for a given crop, sizes indicated for similar crops are generally used or are stipulated empirically by the researcher. This form of definition inflates the experimental error, because the sample and portion sizes vary according to the culture used. For forage peas, a plot size of 5.03m^2 is indicated to assess the green mass of the crop (Cargnelutti Filho et al., 2015). For the variables number of pods per plant and mass of pods per plant, no data were found in the literature on the estimation of plot size to evaluate these variables leading to a wide variation in plot sizes used in the work with the crop.

The plot sizes used by (Cardoso et al., 2012; Zhang et al., 2016; Santos et al., 2018; Singh et al., 2019) ranged from 10 to 420 plants per plot, which were higher than those obtained in the present study, thus indicating greater reliability in the published information. However, Carvalho et al., (2012), Garcia et al., (2010), Mahieu et al., (2009) and Oliveira et al., (2011) used a plot size ranging from one to six plants; these values are below what was estimated in the present study, and may have led to less experimental precision in these works.

3.5.3. Sample size

In studies with pea culture, several studies were found using different sample sizes ranging from one to 25 plants sampled (Mahieu et al., 2009; Oliveira et al., 2011; Carvalho et al., 2012; Roro et al., 2016; Zhang et al., 2016), which causes a variation in experimental precision. For pea culture, eight plants are indicated in the direction of the line for the assessment of NPP and MPP with a confidence interval (D%) equal to 20% of the average for the grouped crops, that is, for the variable NPP, it is necessary carry out the census of all of the plot (100% of the plot) whereas for the variable MPP the sampling must be carried out for 88.8% of the total plot. Thus, the correct use of the sample size allows the researcher to increase the reliability of the results obtained, in addition to reducing the time with labor and resources used.

3.5.4. Number of repetitions

In the different studies with the pea culture, both in completely randomized designs and in randomized blocks, a number of repetitions empirically stipulated by the researchers have been used, leading to a great variation in the number of repetitions used and causing a low experimental precision. Khalil et al (2020) in studies of pea culture, used four treatments with 10 repetitions. Ochoa et al., (2017) used a randomized block design in his study with 21 treatments and three replications. Oliveira et al., (2011) used a completely randomized design with five treatments and four replications.

For forage peas, the number of repetitions for the green mass variable has already been estimated, with four repetitions to evaluate up to 50 treatments in completely randomized designs and randomized blocks with differences between treatment means of 32.4% of the experiment average (Cargnelutti Filho et al., 2015). For the NPP and MPP variables estimated in the present work, it is 10 and 12 repetitions, respectively, are required to evaluate up to 20 treatments in the randomized block design and for incomplete block designs up to 100 treatments, for significant differences of 35% between treatment means. In addition, from the plot size of eight plants for the variable NPP and nine plants for MPP, the researcher can establish the relationship between "*i*" treatments and "*d*" minimum differences between treatment averages to be detected as significant at 5% of probability by the Tukey test, obtaining so the appropriate number of repetitions for the experiment and thereby increasing the reliability of the results obtained.

Obtaining the sufficient number of repetitions per treatment requires that the following conditions are met: (1) the experimental units must be repeated in time or space or both, (2) each experimental unit must receive the treatment, be able to express itself, and be measured independently of all other experimental units, throughout the experiment; and (3) treatments must be randomized, not organized in a systematic or orderly manner (Casler et al., 2015). When the number of repetitions is not adequate, inferences are significantly affected in the experiment (Hurlbert, 1984).

The use a of randomized block design tends to minimize these variations caused by the factors mentioned, leading to greater reliability of the results (Lúcio and Sari, 2017). In many cases, when the number of treatments is high, limitations of financial resources, labor and experimental area available for the implementation of the experiment may occur. In this case, experimental planning is even more important; in addition to preventing design errors, it can prevent experimental execution errors, which generally interfere with several portions in an experiment, occur in different ways and are more subtle than errors of project (Hurlbert, 1984). According to Pimentel-Gomes (2009), under these conditions, the adoption of incomplete blocks can be advantageous both when there are limitations of the experimental area and when the material to be studied are not heterogeneous. However, with this type of planning, not all treatments will be present within each block, because the number of treatments exceeds the number of experimental units per block.

The incomplete block design was proposed by Yates (1954) to evaluate a large number of treatments. This analysis is more complex than that for the randomized block design, with a greater loss of the degrees of freedom of the residual. However, there is a reduction in the residual mean square (experimental error), causing more accurate experiments (Pimentel-Gomes, 2009). Thus, when the experiment has more than 20 treatments, the use of incomplete block should be considered, because it provides greater experimental precision with less use of resources.

In the present study, when the experiment has more than 20 treatments (Table 6 and 7), it is recommended to use incomplete block design in the analysis, this practice will increase the accuracy of the evaluated results. In this type of design each treatment average is estimated with the same precision and all paired comparisons between two treatment averages are equally sensitive (Montgomery, 2017). Silva et al (2014) evaluated the same number of treatments using two experimental designs (complete and incomplete) to verify the agreement between the data. The experiment carried out in the balanced incomplete block design presented similar average scores in comparison to the use of the same methodology conducted in the balanced complete block design.

The residual degrees of freedom of the incomplete block design will be different from the random block design when in the incomplete project the experiment requires a greater number of repetitions to complete the evaluation of the entire block (Silva et al., 2014); on the contrary they will be the same in two designs. The incomplete block design is an alternative for the evaluation of a greater number of treatments, without limiting the experiment or losing information (Silva et al., 2014), and should be considered when the characteristics of the experiment allow,such as differences in environmental conditions, including soil type, climate and agronomic management practices.

Even though the use of complete blocks is the most used in agricultural experiments, its improper use can lead to an increase in the estimation of experimental errors directly affecting the estimates and results (Stroup et al., 1994). More flexibility can be introduced, allowing rows or columns to form incomplete blocks (Piepho et al., 2015) and increase the accuracy of the results

3.6 CONCLUSIONS

The plot size for evaluating the number of pods per plant and the mass of pods per plant for pea cultivation is eight and nine plants, respectively.

The sample size for evaluating the number of pods per plant and the mass of pods per plant is eight plants in the direction of the line with a half-width of the 20% confidence interval of the mean.

For the variables number of pods per plant and pod mass per pea plant, 10 and 12 repetitions are required, respectively, to evaluate up to 20 treatments in a randomized block design and in the incomplete blocks design with up to 100 treatments for significant differences of 35% between treatment averages.

3.7 SUPPLEMENTAL MATERIAL

Supplemental material for this article is available online. It contains six tables, they are the tables with all the values, more complete and explanatory.

3.8 ACKNOWLEDGEMENTS

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3.9 CONFLICT OF INTEREST

The author declares no conflict of interest.

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4 ARTIGO 3 –GROWTH CURVE PEA IN DIFFERENT SEASONS AS A FUNCTION OF ACCUMULATED THERMAL SUM

Submetido para o periódico: Revista Ceres

Situação: Em revisão

Growth curve pea in different seasons as a function of accumulated thermal sum

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4.1 ABSTRACT

The objective of this study was to determine the performance of peas grown in the field, in three growing seasons, by adjusting the nonlinear logistic model and its critical points. Uniformity trials were conducted in the field in the years 2016, 2017 and 2018 in the experimental area of the Crop Science Department of the Federal University of Santa Maria. The cultivar used was the Pea Grain 40. The values of the average mass of pods per plant (g plant^{-1}), obtained in each harvest, were accumulated successively for each row of cultivation. After adjusting the nonlinear logistic model, the average pod mass per plant as a function of the accumulated thermal sum and the critical points were estimated by the partial derivatives of the adjusted function. The pea crop is influenced by environmental conditions, which interferes with the crop cycle and productivity. Season 1 was the most productive, with maximum increases in production in the shortest period (592.5 °C days^{-1} to produce 119.52g plant^{-1}), causing a high production peak in relation to the other seasons analyzed. The adjustment of the logistic model allowed to describe the pea production cycle over time at different growing seasons.

Keywords: *Pisum sativum*, thermal sum, production rate, non-linear models.

4.2 INTRODUCTION

The pea (*Pisum sativum* L.) is an annual herbaceous legume, and when vegetables are harvested green, they have multiple crops in the cycle. Its grains are rich in proteins, carbohydrates and some minerals, where this nutritional content may range according to genetic factors and the growing environment (Khan et al., 2016). Its vegetative cycle depends on the cultivar and the environmental conditions necessary for its development, ranging from 90 to 140 days (Nascimento, 2016).

In 2018, about 21.2 million tons of green peas were harvested in the world, in an area of 2,743,867 ha, where the three countries with the highest green pea production are China, India and the United States, respectively, being responsible for about 11.8 million tons (FAOSTAT, 2020). In Brazil, in 2018, 2813 tons of dry peas were harvested in an area of 837 hectares, where the main producers of the crop are Minas Gerais, Rio Grande do Sul and Distrito Federal, respectively, reaching a total production of 2544 tons (IBGE, 2020). However, for green peas, data on production, planted area and harvested area were not found.

The production of the pea crop is strongly affected by climatic conditions, mainly by temperature, radiation and humidity (Roro et al., 2016). The ideal temperature for its development is between 13 °C and 18 °C, where temperatures above 27 °C impair productivity. To cultivate a short cycle, it is possible to obtain an average of 200 mm to 400 mm of water and 700 to 850 degree-days throughout the production cycle and related statistics above 80%, which can be indirectly and negatively a crop production (Nascimento, 2016).

In general, plants respond non-linearly to air temperature (Paine et al., 2012). In this way, the pea culture, which has a temperature as the main determining factor of production, needs to have a greater detail of its cycle and mainly of the description of the production of the culture over time. A suitable biological time measure is the accumulated thermal sum, being possible to simulate the consequence of air temperature on the growth and development of plants (Mendonça et al., 2012).

In crops of multiple harvests, when their production is accumulated throughout the production cycle, it is common to present sigmoid responses, typical of non-linear models (Lúcio et al., 2016; Sari et al., 2018; Diel et al., 2019b). In addition, the accumulation of harvests throughout the production cycle contributes to the decrease in the number of observations with zero values, common in these types of crops. In a database with high amounts of zero values, problems occur in meeting the assumptions of the analysis of variance, with an advantageous alternative being the evaluation using non-linear regression models (Lúcio et al., 2016; Sari et al., 2018; Diel et al., 2020).

Nonlinear regression models are indicated to study the response of cultures over time, as they allow inferences to be made from the estimates of parameters and critical points, which have biological interpretations (Mischan and Pinho, 2014; Sari et al., 2018). To adjust nonlinear regression models, it is necessary to meet the assumptions of normality, heteroscedasticity and residue independence. When there are controversies regarding the fulfillment of the model's assumptions, the use of the bootstrap resampling technique which generates confidence intervals is an alternative to the inferential process and also a diagnostic tool (Souza, 1998; Souza et al., 2010), being the best way to analyze the distributional properties (Ratkowski, 1983).

Several studies using non-linear models to describe crop production over time have already been developed as for *Allium sativum* (Reis et al., 2014), *Lycopersicon esculentum* (Lúcio et al., 2015b, 2016) *Fragaria* x *ananassa* (Diel et al., 2019b), *Capsicum chinense* (Diel et al., 2020), *Phaseolus vulgaris* (Lucio et al., 2016) *Cucurbita pepo* and *Capsicum annuum* (Lúcio et al., 2015a). For the pea crop, no studies were found on the description of crop production over time.

Therefore, the objective of this study was to determine the performance of peas grown in the field, in three growing seasons, by adjusting the nonlinear logistic model and its critical points.

4.3 MATERIAL AND METHODS

Uniformity tests were carried out in the field in the years 2016, 2017 and 2018 in the experimental area of the Crop Science Department at Federal University of Santa Maria – UFSM (S: 29° 42' 23"; W: 53° 43' 15" 95 meters above sea level) in the municipality of Santa Maria – RS, Brazil, where according to the Köppen classification climate of the region is the Cfa type - rainy temperate, with rains well distributed throughout the year and subtropical from the thermal point of view (Alvares et al., 2013).

The soil of the experimental area is classified as Alfisols (Soil Survey Staff, 1999). The soil preparation in the experimental area was carried out with the rotary hoe, and the basic fertilization was carried out according to the soil analysis, following the technical recommendations of the crop (ROLAS, 2004).

The three uniformity tests were carried out on construction sites, without using irrigation. In the first and second years (2016 and 2017), beds with two sowing lines were used, using the spacing of 0.45 m between plants and 0.80 m between rows, with each row consisting of 30 pits, containing four plants per pit, each pit was considered a basic unit (UB). For the year 2018 ridges with a row were used, using the spacing of 0.45 m between plants and 0.80 m between the ridges, and each row was composed of 30 pits, containing four to five plants per pit where, each pit was also considered a UB. The cultivar used was Pea Grain 40, which has an indeterminate growth habit, with a cycle of 75 to 90 days and a cylindrical pod. The sowing was carried out on the dates of 05/03/2016, 05/16/2017 and 04/06/2018.

The pods were harvested in all UBs when they had a light green color. After being collected, they were packed in identified plastic bags and sent to the laboratory for counting and measurement the pods mass (PM, in g).

Dataset and models Fitting

The values of the average mass of pods per plant (g plant^{-1}), obtained in each harvest, were accumulated successively for each row of cultivation. The logistic model was selected in other works that suggest this Logistic model for multiple harvest vegetables (Lúcio et al., 2015a; Diel et al., 2019; Sari et al., 2018). The parameterization of the adjusted logistic model was: $yi^1 = \frac{\beta_1}{1+e^{(\beta_2-\beta_3 x_i)}} + \varepsilon_i$ ^1Y_i = the dependent trait (accumulated number or weight of pods per plant); X_i = accumulated thermal sum (STa), in degree days, an elapsed time of transplant of seedlings to harvest (independent trait); β_1 represents the horizontal asymptote, that is, the point of stabilization of plant growth; β_2 is the parameter that indicates the distance (in relation to abscissa) between the initial value and the asymptotes; β_3 is a parameter associated with the growth rate; and ε_i represents the random error.

The parameter estimates were obtained using the ordinary least squares method, using the Gauss-Newton iterative process. Subsequently, the adjusted determination coefficient (R²aj) and the Akaike Information criterion were estimated. After adjusting the model, the confidence interval (CI) was calculated by bootstrap, with 10,000 resamples using the *nls tools* package in software R. Due to the violation of one of the assumptions of the statistical model in season 2 (normality of errors), it was decided to generate intervals using the bootstrap resampling method.

The coordinates (x, y) of the critical points of the logistic growth curve, known as the maximum acceleration point (MAP), the inflection point (PI), the maximum deceleration point (MDP) and the asymptotic deceleration point (ADP) were obtained by making the derivatives equal to zero $\frac{d^2Y}{dx^2}$, $\frac{d^3Y}{dx^3}$ and $\frac{d^4Y}{dx^4}$, according to the methodology described in Mischan et al., 2011. Statistical and graphical analyzes were performed using the software R (R Core Team, 2019).

4.4 RESULTS

For season 1, the maximum temperature was 33.2 ° C, the minimum temperature was 0 ° C and the average temperature was between 6.9 ° C to 28.1 ° C (Figure 1a), while radiation oscillated from 0 to 10 W m^{-2} and the total precipitation during the culture cycle was 345.2 mm (Figure 1b). For season 2, the temperature fluctuated from -1.2 ° C to 35.4 ° C, while the average temperature was between 6.2 ° C to 28.7 ° C (Figure 1c), whereas the radiation fluctuated from 0 to 10.2 W m^{-2} and precipitation during the culture cycle was 654 mm (Figure 1d). While for season 3 the temperature fluctuated from -1 ° C to 35.4 ° C, and the average temperature fluctuated from 5.8 ° C to 29.2 ° C (Figure 1e) while the radiation from 0 to 10.4 W m^{-2} and the total precipitation during the cycle was 496.5 mm (Figure 1f).

In the logistic growth model adjusted for pod mass (g $plant^{-1}$), the assumption of the non-linear model normality of errors was not met for the second growing season, in addition to presenting a low coefficient of determination. To circumvent this problem, the model was adjusted by bootstrap resampling (Table 1).

The adjustment of the parameters of the logistic model and the critical points, estimated by bootstrap resampling, allowed comparisons between the pea cultivation times (Table 2 and Figures 2 and 3). It is possible to observe that the highest production of pods was obtained in season 1, which showed production of 119.52 g plant $^{-1}$, while the lowest production was found for season 3 (52.59 g plant $^{-1}$). Season 2, on the other hand, presented an average production of 69.38 g $plant^{-1}$ and these values can be observed through the parameter β_1 (Table 2 and figure 2). Season 1, further to being more productive, was still significantly higher than the seasons 2 and 3, which did not differ (Figure 2). These results may have occurred due to the frequency and amount of rainfall in each period, in addition to the amount of solar radiation (Figure 1).

In relation to the pod production rate (β_3) and the concentration of production, it was found that in season 1 the culture spent less time producing, but obtained the highest production according to the β_1. In the season 3 the production remained for a longer time, but with lower production than season 1 while in season 2 the culture spent a longer time producing when compared to other seasons, but with a low production throughout the period (Table 1, figure 2 and 3).

As for the critical points of the logistic model, the point of maximum acceleration (MAP) showed differences between the growing seasons indicating that season 1 showed maximum increases in production in a shorter period, needing 592.5 ° C days^{-1} to produce 119.52g, causing a high production peak in relation to the other analyzed seasons while season 3 required 897.80 ° C days^{-1} to produce 52.59g. This can be confirmed through the inflection point (PI), where it is observed that the PI was reached earlier in season 1 in relation to the other seasons, indicating greater precocity, since this parameter indicates where the maximum peak of production occurs (Table 1 and figure 3).

The maximum deceleration point (MDP) and the asymptotic deceleration point (ADP) showed a difference between the periods evaluated where it can be seen that season 1 decreased its production earlier than seasons 2 and 3, needing fewer degrees days to complete the cycle, whereas in seasons 2 and 3 these points were similar (Table 2 and figure 3), due to the characteristics of the environment in these times.

4.5 DISCUSSIONS

The ideal temperature for the development of the pea oscillates between 13 °C and 18 °C, the seeds of the crop germinate with temperatures above 4 °C and their development is strongly influenced by the degree-days (Nascimento, 2016). Already temperatures above 31

°C in the critical period of the crop, which is six days after opening the flower, reduce the number of seeds per pod (Jeuffroy et al., 1990) and temperatures below 0 °C reduce germination and increase the mortality of cultivars not resistant to cold (Zhang et al., 2016). It can be observed that in the three growing seasons of the crop, a large temperature variation was observed, where the plants were affected by temperatures below and above the optimum temperature for their development in all growing seasons, which may have led to low crop productivity.

Other factors that can influence crop production are the availability of water and radiation. In times of cultivation when there is a shortage of rain, they reduce the weight of 1000 seeds, the number of pods per plant (Santín-Montanyá et al., 2014), of the specific leaf area (Roro et al., 2016) presenting a drop in production of 38.50% when the water deficit occurs in the vegetative phase and 43.04% in the reproductive phase, which the characteristics of the crop are favored when the soil is kept moist, close to the field capacity (Carvalho et al., 2012). Furthermore, UV radiation affects the number of branches per plant and the leaf area in dry seasons (Roro et al., 2016). Thus, decreasing the number of flowers in the plant and consequently decreasing the number of pods, causing a decrease in crop production. As in the present study, the cultivation was carried out in rainfed being dependent only on precipitation, which was low and poorly distributed during the culture cycle, causing low productivity, together with the other factors mentioned above.

The use of non-linear regression models makes it possible to know the development of culture through its growth curves which are represented by a sequence of measurements over time. (Mischan and Pinho, 2014). Thus, the knowledge of this curve allows us to determine the production cycle and to carry out the best management for the studied culture. The use of non-linear models, such as logistics, can provide information about the cycle and the development of culture, which would not be possible with the use of linear regression models (Diel et al., 2020).

When the model's assumptions are not met, the adjustment with the bootstrap resampling can be performed in order to circumvent this problem and make the estimates of the parameters of the non-linear model to be reliable and represent the reality of the culture cycle (Ratkowski, 1983; Souza, 1998; Souza et al., 2010). As for the difference in pod production between the growing seasons represented by the parameter β_1 of the logistic model, the highest production was found in season 1 while the other seasons had a lower production which can be explained by the environmental conditions in those times, such as high temperatures and also negative temperatures, in addition to rains that are not widely distributed throughout the cycle cultivation, negatively affecting crop production.

Great variability is noticed in the production of the pea crop. The yield depends on the cultivar used and the cultivation techniques, where for green grains the productivity of the pea ranges from 3.0 ton ha^{-1} to 7.0 ton ha^{-1} (Nascimento, 2016). Schiavon et al., (2018) found average productivity of 929.7 kg ha^{-1} for pea cultivation when studying 35 double-purpose pea genotypes. Already Gassi et al., (2009) studying different spacing between plant and number of rows found that fresh mass production of pods ranging from 5.23 ton ha^{-1} to 7.48 ton ha^{-1} for pea cultivation.

The parameters β2 and β3 and concentration, indicate the precocity and rate of crop production were different in each growing season and that the crop cycle increased at times when the temperature had a greater range of oscillation and that when the crop was subjected to very low temperatures, as in the case of seasons 2 and 3, the production cycle of the crop was greater. Similar results were found by Vieira et al., (2000) when studying different planting times for the pea crop, found that very low temperatures can prolong the reproductive period and increase the crop cycle. In addition, the cycle and the production can be reduced sooner irrigation stop (Marquelli et al., 1990), which may have occurred in this study, since the 1st season was the least precipitation.

According to Sari et al., (2018), values of β_3 higher increases the slope of the curve and reduce the time between the beginning and end of the harvests, the production rate is higher and the PI happening earlier which takes less time between the MAP and the MDP, indicating that this parameter can be used to interpret the precocity of production. This was contacted in the present study for season 1, indicating that at that time you had more production are concentrated in less time. Furthermore, in season 1, ADP was earlier than in other seasons, that is, the decrease in production occurred earlier. Resende and Vieira (1999) testing different pea cultivation times found that in the year in which they had lower temperatures during the reproductive period, they had an increase in the cycle of a pea cultivar. Second Nascimento, (2016) the vegetative cycle of the crop depends on the cultivar and the climatic conditions necessary for its development, ranging from 90 to 140 days.

Growth models allow, in addition to defining the most productive season or genotype, it is also elucidated which of the seasons evaluated to have the best production indicators, such as precocity and the production rate in each season. Hypothetically, the choice of the best growing season or genotype will depend, in addition to the total production, on the producer's planning to insert the product sooner into the consumer market and extend it for a long period or have maximum production rates with a high peak and production in less time.

4.6 CONCLUSIONS

The pea crop is influenced by environmental conditions, which interferes with the crop cycle and productivity.

Season 1 was the most productive, with maximum increases in production in the shortest period (592.5 °C days^{-1} to produce 119.52g plant^{-1}), causing a high production peak in relation to the other seasons analyzed.

The adjustment of the logistic model allowed to describe the pea production cycle over time in different growing seasons.

4.7 ACKNOWLEDGEMENTS

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Table 1: *p* values for normality, heteroscedasticity and error independence tests, coefficient of determination, and Akaike information criterion of the logistic model adjusted for pod mass (g plant^{-1}) for peas in three growing seasons. SW (Shapiro Wilk), BP (Breush Pagan), DW (Durbin Watson), R^2aj (Adjusted coefficient of determination), AIC (Akaike Information Criterion).

Season	SW	BP	DW	R^2aj	AIC
Season 1	0.350579	0.204827	0.334	0.928792	193.04
Season 2	0.022831	0.839657	0.396	0.426235	273.52
Season 3	0.453953	0.400007	0.540	0.648139	98.29

Table 2: Parameters of the estimated Logistic model for the mass of pea pods grown in three planting times (β_1= represents production, β_2 = in biological terms it represents the precocity of production and β_3 = represents the rate of pod production) and its critical points (PI = inflection point, MAP = maximum acceleration point, MDP = maximum deceleration point, ADP = asymptotic deceleration point.

Season	β_1	β_2	β_3	PI	MAP	MDP	ADP
Season 1	119.52	15.91	0.02	645.98	592.50	699.45	739.06
Season 2	69.38	11.03	0.01	912.70	803.69	1021.72	1102.46
Season 3	52.59	19.90	0.02	961.41	897.80	1025.03	1072.15

Figure 1 - Maximum, average and minimum temperature, radiation and precipitation for the growing years 2016, 2017 and 2018. (a) Maximum, average and minimum temperature and (b) radiation and precipitation for season 1, (c) maximum, average and minimum temperature and (d) radiation and precipitation for season 2, (e) maximum, average and minimum temperature and (f) radiation and precipitation for the season 3.

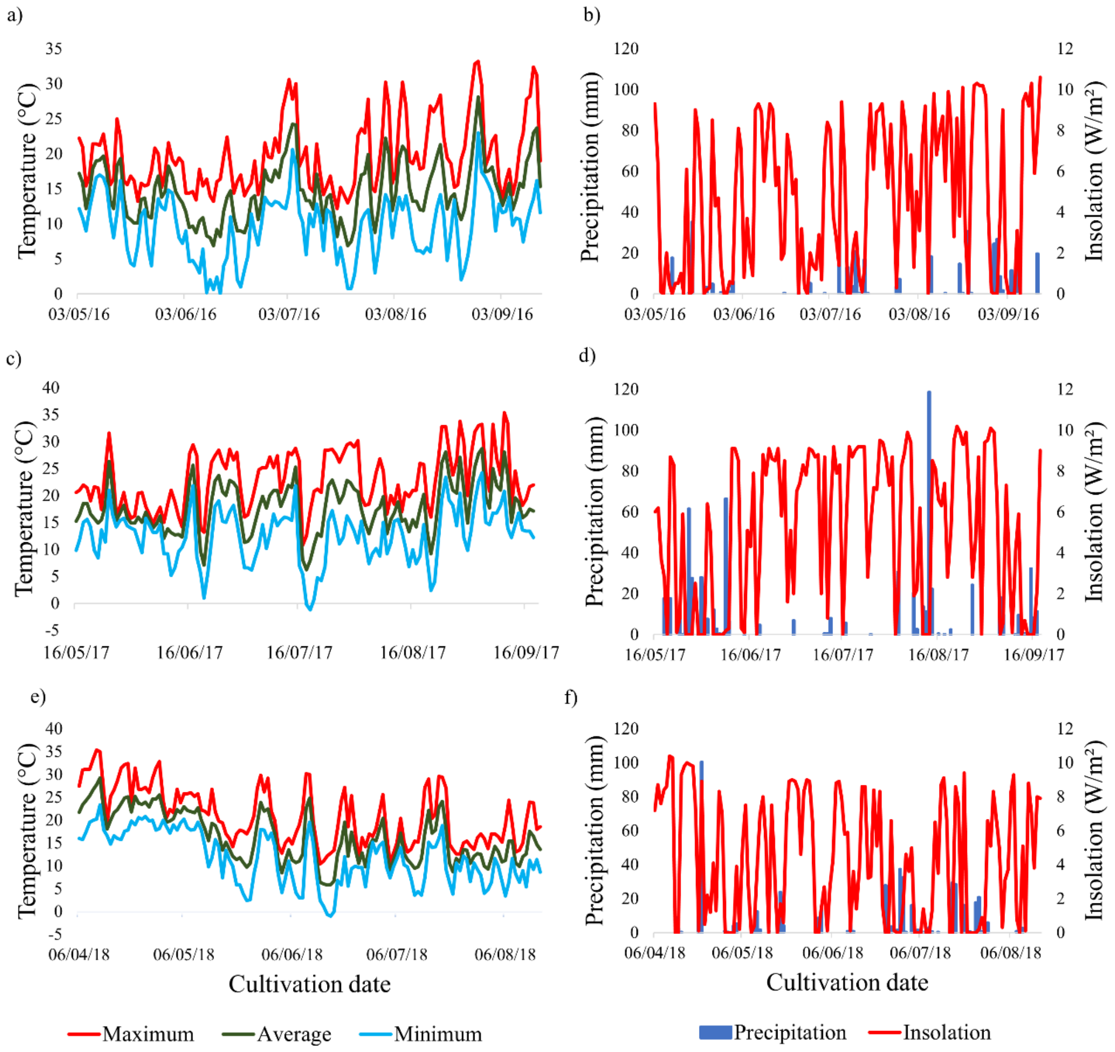


Figure 2 - Parameters of the estimated Logistic model ($\beta_1, \beta_2, \beta_3$) and their bootstrap confidence intervals for pod mass (g plant^{-1}) and the concentration of harvests determined by the differences between MAP and MDP (MDP-MAP) for the cultivation of peas grown three growing seasons.

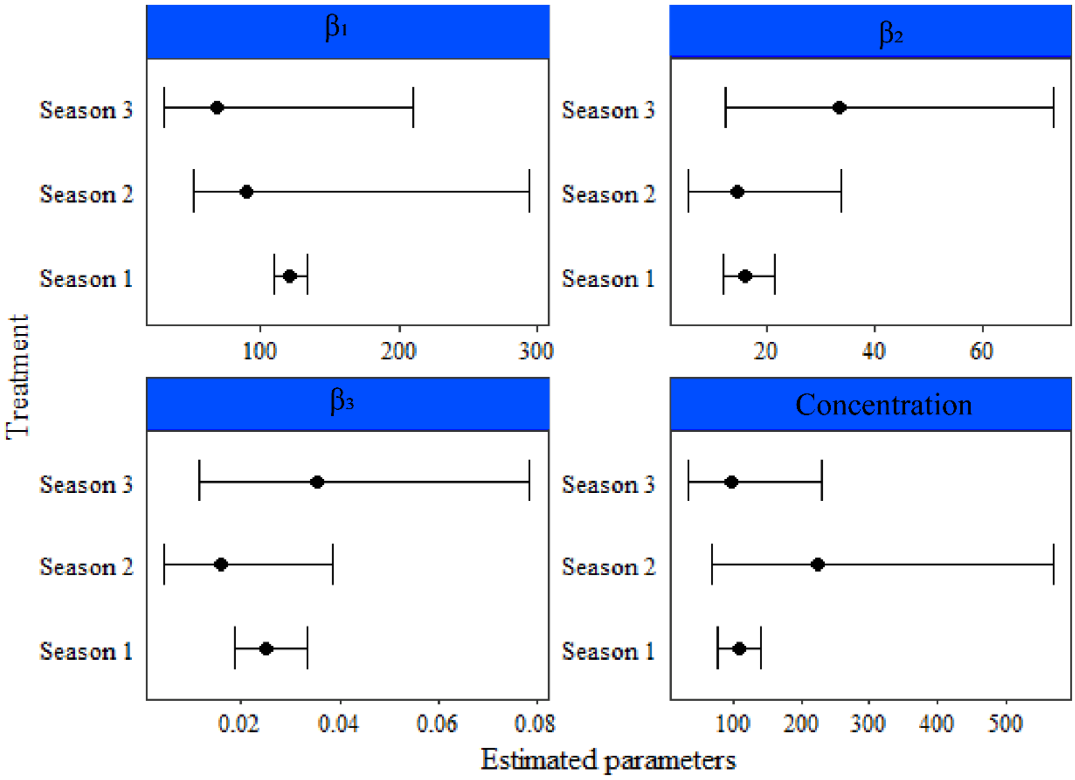
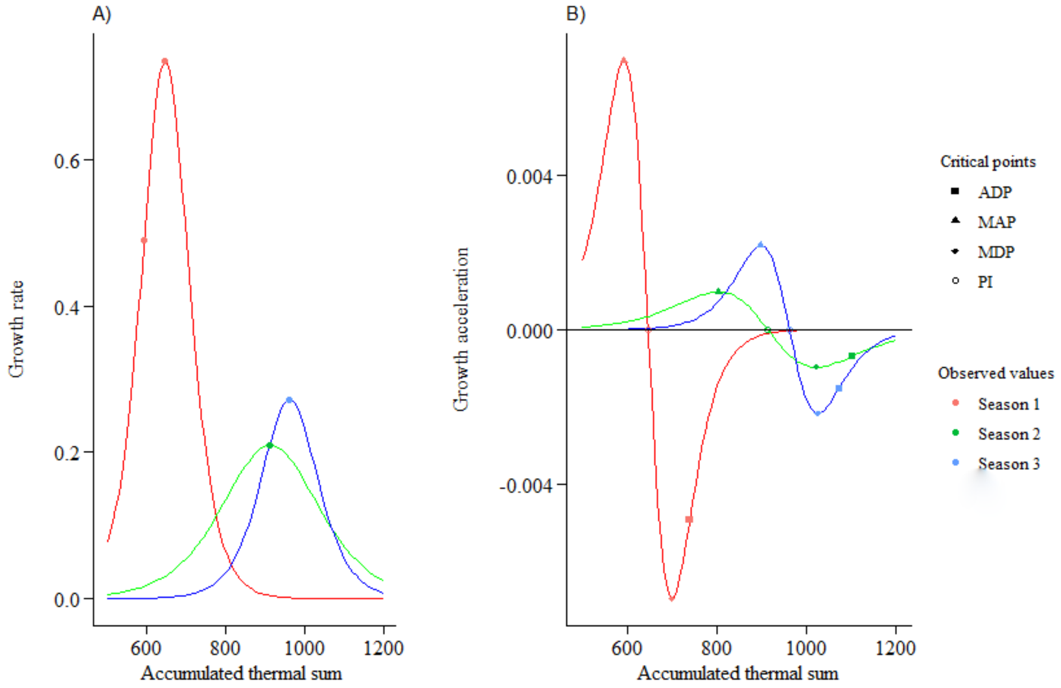


Figure 3 - Logistic model adjusted for pea pod mass in three growing seasons (A), fruit production rate and (C) critical points of the model (PI = inflection point, MAP = maximum acceleration point, MDP = maximum deceleration point, ADP = asymptotic deceleration point).



5 CONSIDERAÇÕES GERAIS

Tendo em vista o melhor planejamento experimental para a cultura da ervilha e o aumento da precisão experimental, este estudo utilizou diferentes técnicas experimentais para fornecer importantes informações sobre a cultura, permitindo o pesquisador obter maior precisão em seus experimentos, além de diminuir custos e tempo a serem utilizados.

Na análise de trilha em todas as colheitas e épocas estudas, as variáveis massa de vagens e número de grãos apresentaram as maiores relações de causa e efeito sobre a variável massa de grãos de ervilha. Deste modo, quanto maior a massa de vagens e número de grãos por planta, maior será a massa de grãos por planta. Assim essas variáveis podem ser utilizadas para a seleção de plantas mais produtivas, pois essas variáveis apresentam maior efeito direto sobre a produção de massa de grãos de ervilha.

Para a análise de correlação canônica em todas as colheitas e épocas estudadas, os grupos de vagens e grãos apresentaram alta correlação canônica e cargas canônicas altas e negativas em ambos os grupos, indicando que estes grupos são dependentes e podem ser utilizados para seleção de caracteres. Assim a análise de correlação canônica mostrou que as variáveis de vagens podem ser utilizadas como uma alternativa na seleção de plantas com maior produção de grãos.

Já para as estimativas do tamanho de parcela e do tamanho de amostra, o acúmulo das colheitas possibilitou a redução da variabilidade das variáveis número de vagens por planta e massa de vagens por planta entre as filas de cultivo e épocas avaliadas. Assim o maior tamanho de amostra e maior tamanho de parcela nas colheitas acumuladas entre as épocas de cultivo, foram indicados como referência para estudos com a cultura da ervilha, pois esse valor já engloba todas as variações existentes entre as filas de cultivo e épocas de cultivo, aumentando assim a precisão experimental, além de reduzir a mão de obra, tempo e recursos utilizados.

Com os números de repetições estimados para as variáveis número de vagens por planta e massa de vagens por planta o pesquisador pode selecionar qual o número adequado de repetições a ser utilizado em seu experimento, relacionado o seu número de tratamentos com precisão desejada, tanto para experimentos em blocos ao acaso como para blocos incompletos, obtendo assim uma melhor precisão experimental.

O modelo de regressão não linear logístico possibilitou descrever a produção da cultura da ervilha ao longo do tempo em diferentes épocas de cultivo, permitindo assim selecionar épocas que apresentem maiores produções, além da precocidade e a taxa de produção de frutos. Essa metodologia de análise é uma abordagem que permite maiores inferências ao se utilizar apenas a produção final em uma análise de variância por exemplo. Assim, uma caracterização completa do ciclo de produção pode ser realizada, permitindo que o produtor selecione a época de cultivo mais adequado, de acordo com a sua necessidade.

6 CONCLUSÕES GERAIS

A produção de ervilha apresentou a mesma tendência nas relações entre as variáveis, nas diferentes colheitas e épocas de cultivo, sofrendo interferência das condições ambientais.

As variáveis massa de vagens e números de grãos são as variáveis com maiores relações de causa e efeito sobre a massa de grãos e podem ser utilizadas para a seleção indireta de plantas mais produtivas.

Plantas com menor massa de vagens proporcionam vagens com menor número de grãos e menor massa de grãos de acordo com a correlação canônica.

O tamanho de parcela para avaliar o número de vagens por planta e massa de vagens por planta para a cultura da ervilha é de oito e nove plantas, respectivamente.

O tamanho de amostra para a avaliar o número de vagens por planta e massa de vagens por planta é de oito plantas na direção da linha com uma semi-amplitude do intervalo de confiança de 20% da média.

Para as variáveis número de vagens por plantas e massa de vagens por planta de ervilha são necessárias 10 e 12 repetições, respectivamente, para avaliar até 20 tratamentos no delineamento de blocos ao acaso e no delineamento blocos incompletos com até 100 tratamentos para diferenças significativas de 35% entre médias de tratamentos.

A cultura da ervilha é influenciada pelas condições ambientais, as quais interferem no ciclo e na produtividade da cultura.

A época 1 foi a mais produtiva, apresentando incrementos máximos na produção em menor período (592,5 °C dias^{-1} para produzir 119,52g planta^{-1}), ocasionando um pico de produção elevado em relação as outras épocas analisadas.

O ajuste do modelo logístico permitiu descrever o ciclo produtivo da ervilha ao longo do tempo nas diferentes épocas de cultivo.

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APÊNDICE A - MATERIAL COMPLEMENTAR PARA O ARTIGO 2.

Supplemental Table S1. Plot size (Xo, in plants) and coefficient of variation in plot size in parentheses (CVXo, in%) between individual and grouped crops for the number of pods per plant (NPP) and the p-value of the Bartlett's test between rows in each crop in three years of cultivation for pea cultivation.

		Harvests				
	Row	C1	C2	C3	C1+C2	C1+C2+C3
2016	F1	9(19.1)	10(21.3)	9(20.7)	7(16.5)	7(16.6)
	F2	8(17.6)	5(12.0)	7(15.4)	4(9.1)	4(9.0)
	F3	10(22.1)	10(22.6)	7(16.5)	10(21.4)	8(18.1)
	F4	7(16.5)	4(9.1)	9(16.7)	3(7.4)	3(7.6)
	F5	7(16.7)	5(11.8)	8(17.8)	5(10.1)	4(9.8)
	F6	11(24.1)	7(16.1)	8(16.9)	7(14.9)	6(14.0)
	F7	9(19.7)	5(11.4)	5(11.9)	5(10.7)	4(8.4)
	F8	9(20.2)	5(10.1)	5(12.0)	4(8.6)	3(7.5)
	p-value[1]	<0.001	<0.001	<0.001	<0.001	<0.001
2017	F1	3(7.0)	7(15.9)	4(9.8)	3(7.3)	2(5.0)
	F2	3(7.6)	13(29.9)	6(12.4)	4(8.1)	4(8.1)
	F3	3(6.4)	6(12.8)	6(12.7)	2(3.5)	2(4.2)
	F4	5(11.3)	3(6.7)	8(17.1)	4(8.8)	4(7.9)
	F5	9(19.4)	10(21.7)	7(16.0)	7(16.4)	7(15.8)
	F6	10(22.4)	9(20.1)	6(13.1)	7(16.0)	7(14.9)
	F7	8(17.8)	6(13.1)	5(11.3)	4(9.7)	4(8.0)
	F8	9(21.2)	6(12.8)	4(9.7)	5(12.0)	5(10.2)
	F9	5(12.1)	5(10.5)	7(14.8)	4(8.9)	4(9.2)
	F10	4(9.7)	6(13.2)	7(14.7)	4(9.0)	4(8.5)
	p-value	<0.001	0.0001	0.0225	<0.001	<0.001
2018	F1	9(20.9)	10(21.5)	6(13.9)	7(14.9)	4(9.5)
	F2	6(13.7)	11(24.2)	5(11.5)	6(13.1)	5(11.7)
	F3	6(13.5)	10(21.8)	7(16)	5(11.8)	5(10.6)
	F4	5(11.7)	8(18.1)	8(17.2)	5(12.0)	4(9.9)
	F5	11(24.5)	9(20.3)	7(15.2)	8(18.5)	5(11.4)
	p-value	0.0599	0.2300	0.0187	0.8130	0.931

[1]: *p-values* lower than 0.05 shows heterogeneous variances between rows of cultivation within each individual or grouped harvest.

Supplemental Table S2. Plot size (Xo, in plants) and coefficient of variation in plot size in parentheses (CVXo, in%) between individual and grouped crops for the mass of pods per plant (MPP, in g) and the p-value of Bartlett's test between rows in each crop over three years of cultivation for pea cultivation.

		Harvests				
	Row	C1	C2	C3	C1+C2	C1+C2+C3
2016	F1	9(19.6)	9(21.1)	9(20.2)	7(16.7)	7(16.2)
	F2	8(18.0)	5(10.8)	8(17.7)	4(8.0)	4(8.1)
	F3	11(24.4)	10(22.7)	8(17.9)	10(21.9)	9(19.7)
	F4	8(17.6)	4(9.5)	9(19.5)	4(8.1)	4(7.9)
	F5	8(18.4)	6(12.6)	10(22.7)	5(10.7)	5(10.5)
	F6	11(25.5)	7(16.0)	9(19.6)	7(14.7)	7(14.6)
	F7	9(20.5)	5(11.6)	6(12.8)	5(11.2)	4(9.1)
	F8	10(21.5)	5(11.4)	6(12.4)	4(9.2)	4(8.3)
	p-value	<0.001	<0.001	<0.001	<0.001	<0.001
2017	F1	4(9.2)	6(12.6)	4(9.4)	3(7.5)	2(5.1)
	F2	4(9.1)	13(28.4)	7(14.8)	4(9.5)	4(9.4)
	F3	3(6.8)	6(14.0)	8(17.2)	2(4.4)	2(5.6)
	F4	6(14.2)	3(6.9)	8(17.0)	5(11.0)	4(9.9)
	F5	9(20.4)	11(25.7)	10(21.3)	8(18.6)	8(18.6)
	F6	9(20.5)	10(22.5)	6(12.9)	6(14.1)	6(13.0)
	F7	5(11.2)	6(13.7)	5(12.0)	5(10.1)	4(9.1)
	F8	9(19.7)	6(13.0)	5(10.2)	5(11.2)	5(10.1)
	F9	5(11.8)	6(12.9)	7(15.7)	4(10.0)	5(10.3)
	F10	4(9.7)	6(13.2)	7(14.7)	4(9.0)	4(8.5)
	p-value	<0.001	<0.001	0.0201	<0.001	<0.001
2018	F1	9(19.5)	10(22.1)	7(15.9)	6(13.5)	4(9.7)
	F2	7(15.1)	11(24.2)	8(18.4)	6(13.2)	6(13.0)
	F3	6(14.1)	10(22.4)	7(16.1)	5(12.1)	5(10.8)
	F4	5(11.6)	10(21.3)	7(16.6)	6(12.4)	5(10.1)
	F5	11(25.0)	9(21.0)	6(14.3)	9(19.5)	6(12.4)
	p-value	0.1530	0.0569	0.0049	0.8720	0.889

[1]: *p-values* lower than 0.05 shows heterogeneous variances between rows of cultivation within each individual or grouped harvest.

Supplemental Table S3. Sample size (in number of plants) between individual harvests (C1, C2 and C3) and grouped crops (C1 + C2 and C1 + C2 + C3) for the number of pods per plant (NPP) in half-width of the interval confidence interval (D% = 5, 10, 15 and 20%) in three years of cultivation for pea cultivation.

		Harvests																			
		C1				C2				C3				C1+C2				C1+C2+C3			
	D%	5	10	15	20	5	10	15	20	5	10	15	20	5	10	15	20	5	10	15	20
2016	F1	9	9	8	7	9	9	8	7	9	9	8	7	7	7	6	6	7	7	6	6
	F2	8	8	7	7	5	4	4	4	8	8	7	6	4	4	3	3	4	4	3	3
	F3	11	11	10	10	10	10	9	9	8	8	7	7	10	10	9	9	9	9	8	8
	F4	8	8	7	7	4	4	3	3	9	9	8	8	4	4	3	3	4	4	3	3
	F5	8	8	7	7	6	6	5	5	10	10	9	9	5	5	4	4	5	5	4	4
	F6	11	11	10	10	7	7	6	5	9	9	8	7	7	6	6	5	7	6	6	5
	F7	9	9	8	8	5	5	4	4	6	6	5	5	5	5	4	4	4	4	3	3
	F8	10	10	9	8	5	5	4	4	6	6	5	5	4	4	3	3	4	4	3	3
2017	F1	3	3	3	3	7	7	7	6	4	4	4	4	3	3	3	3	2	2	2	2
	F2	3	3	3	3	13	13	12	12	6	6	6	5	4	4	4	3	4	4	4	3
	F3	3	3	3	2	6	6	6	5	6	6	6	5	2	2	1	1	2	2	2	1
	F4	5	5	5	4	3	3	3	3	8	8	7	7	4	4	4	3	4	4	4	3
	F5	9	9	8	8	10	10	9	9	7	7	7	6	7	7	7	6	7	7	7	6
	F6	10	10	10	9	9	9	9	8	6	6	6	5	7	7	7	6	7	7	7	6
	F7	8	8	7	7	6	6	6	5	5	5	5	4	4	4	4	3	4	4	4	3
	F8	9	9	8	8	6	6	5	5	4	4	4	3	5	5	5	4	5	5	4	4
	F9	5	5	5	4	5	5	4	4	7	7	7	6	4	4	4	3	4	4	4	3
	F10	4	4	4	3	6	6	6	5	4	4	4	4	4	4	4	3	4	4	4	3
2018	F1	9	9	8	8	10	10	9	9	6	6	6	5	7	7	6	6	4	4	4	3
	F2	6	6	5	5	11	11	10	10	5	5	5	4	6	6	5	5	5	5	5	4
	F3	6	6	6	5	10	10	9	9	7	7	6	6	5	5	5	4	5	5	4	4
	F4	5	5	4	4	8	8	8	7	8	8	7	7	5	5	5	4	4	4	4	3
	F5	11	11	10	10	9	9	8	8	7	7	6	6	8	8	7	7	5	5	5	4

Supplemental Table S4. Sample size (in number of plants) between individual harvests (C1, C2 and C3) and grouped (C1 + C2 and C1 + C2 + C3) crops for the mass of pods per plant (MPP, g) in half-width the confidence interval of the mean (D% = 5, 10, 15 and 20%), in three years of cultivation for the pea culture.

		Harvests																			
		C1				C2				C3				C1+C2				C1+C2+C3			
	D%	5	10	15	20	5	10	15	20	5	10	15	20	5	10	15	20	5	10	15	20
2016	F1	9	9	8	7	9	9	8	7	9	9	8	7	7	7	6	6	7	7	6	6
	F2	8	8	7	7	5	4	4	4	8	8	7	6	4	4	3	3	4	4	3	3
	F3	11	11	10	10	10	10	9	9	8	8	7	7	10	10	9	9	9	9	8	8
	F4	8	8	7	7	4	4	3	3	9	9	8	8	4	4	3	3	4	4	3	3
	F5	8	8	7	7	6	6	5	5	10	10	9	9	5	5	4	4	5	5	4	4
	F6	11	11	10	10	7	7	6	5	9	9	8	7	7	6	6	5	7	6	6	5
	F7	9	9	8	8	5	5	4	4	6	6	5	5	5	5	4	4	4	4	3	3
	F8	10	10	9	8	5	5	4	4	6	6	5	5	4	4	3	3	4	4	3	3
2017	F1	4	4	4	3	6	6	5	5	4	4	4	4	3	3	3	3	2	2	2	2
	F2	4	4	4	3	13	13	12	12	7	7	7	6	4	4	4	3	4	4	4	3
	F3	3	3	3	2	6	6	6	5	8	8	8	7	2	2	2	1	2	2	2	2
	F4	6	6	6	5	3	3	3	2	8	8	7	7	5	5	5	4	4	4	4	4
	F5	9	9	8	8	11	11	10	10	10	10	9	9	8	8	8	7	8	8	8	7
	F6	9	9	9	8	10	10	10	9	6	6	6	5	6	6	6	5	6	6	6	5
	F7	5	5	5	4	6	6	6	5	5	5	5	4	5	5	5	4	4	4	4	3
	F8	9	9	8	8	6	6	6	5	5	5	5	4	5	5	5	4	5	5	4	4
	F9	5	5	5	4	6	6	5	5	7	7	7	6	4	4	4	3	5	5	4	4
	F10	4	4	3	3	6	6	6	5	7	7	7	6	4	4	4	3	4	4	4	3
2018	F1	9	9	8	8	10	10	9	9	7	7	7	6	6	6	5	5	4	4	4	3
	F2	7	7	6	6	11	11	10	10	8	8	7	7	6	6	5	5	6	6	5	5
	F3	6	6	6	5	10	10	9	9	7	7	6	6	5	5	5	4	5	5	5	4
	F4	5	5	4	4	10	10	9	9	7	7	6	6	6	6	5	5	5	5	4	4
	F5	11	11	10	10	9	9	8	8	6	6	6	5	9	9	8	8	6	6	5	5

Supplemental Table S5. Number of repetitions for experiments in the CO in scenarios formed by the combinations of "i" treatments (i = 2, 3, 4, ..., 20) and "d" minimum differences between means of treatments a be detected as significant at 5% probability, by the Tukey test, expressed as a percentage of the average of the experiment (d = 5, 10, 15, ..., 50%), for the variable number of pods per plant, from plot size (Xo = 7 plants) and variation coefficient in plot size (CVXo = 15.8%) for 2017 and plot size (Xo = 5 plants) and variation coefficient in plot size (CVXo = 11.7%) for 2018, for the pea crop.

		d (%)									
	i	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**
2017	2	369	92	41	23	15	10	8	6	5	4
	3	253	63	28	16	10	7	5	4	3	3
	4	239	60	27	15	10	7	5	4	3	2
	5	238	59	26	15	10	7	5	4	3	2
	6	240	60	27	15	10	7	5	4	3	2
	7	244	61	27	15	10	7	5	4	3	2
	8	248	62	28	15	10	7	5	4	3	2
	9	252	63	28	16	10	7	5	4	3	3
	10	256	64	28	16	10	7	5	4	3	3
	11	260	65	29	16	10	7	5	4	3	3
	12	269	67	30	17	11	7	5	4	3	3
	13	267	67	30	17	11	7	5	4	3	3
	14	274	69	30	17	11	8	6	4	3	3
	15	270	68	30	17	11	8	6	4	3	3
	16	277	70	31	18	12	8	6	5	4	3
	17	283	71	32	18	12	8	6	5	4	3
	18	288	72	32	18	12	8	6	5	4	3
	19	294	74	33	19	12	9	6	5	4	3
	20	299	75	34	19	12	9	7	5	4	3
2018	2	204	51	23	13	8	6	4	3	3	2
	3	140	35	16	9	6	4	3	2	2	1
	4	132	33	15	8	5	4	3	2	2	1
	5	132	33	15	8	5	4	3	2	2	1
	6	133	33	15	8	5	4	3	2	2	1
	7	135	34	15	8	5	4	3	2	2	1
	8	137	34	15	9	5	4	3	2	2	1
	9	139	35	15	9	6	4	3	2	2	1
	10	142	35	16	9	6	4	3	2	2	1
	11	144	36	16	9	6	4	3	2	2	1
	12	149	37	17	9	6	4	3	2	2	1
	13	148	37	16	9	6	4	3	2	2	1
	14	152	38	17	9	6	4	3	2	2	2
	15	150	37	17	9	6	4	3	2	2	1
	16	154	39	17	10	7	5	4	3	2	2
	17	157	40	18	10	7	5	4	3	2	2
	18	160	40	18	10	7	5	4	3	2	2
	19	163	41	19	11	7	5	4	3	2	2
	20	166	42	19	11	7	5	4	3	2	2

Supplemental Table S6. Number of repetitions for experiments in the randomized block design, in scenarios formed by the combinations of “i” treatments (i = 2, 3, 4, ..., 20) and “d” minimum differences between means of treatments a be detected as significant at 5% probability, by the Tukey test, expressed as a percentage of the average of the experiment (d = 5, 10, 15, ..., 50%), for the variable mass of pods per plant, from plot size (Xo = 8 plants) and variation coefficient in plot size (CVXo = 18.6%) for 2017 and plot size (Xo = 6 plants) and variation coefficient in plot size (CVXo = 13. %) for 2018, for the pea crop.

		d (%)									
	i	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**
2017	2	513	128	57	32	21	14	10	8	6	5
	3	352	88	39	22	14	10	7	5	4	4
	4	332	83	37	21	13	9	7	5	4	3
	5	331	83	37	21	13	9	7	5	4	3
	6	334	83	37	21	13	9	7	5	4	3
	7	339	85	38	21	14	9	7	5	4	3
	8	345	86	38	22	14	10	7	5	4	3
	9	350	88	39	22	14	10	7	5	4	4
	10	356	89	40	22	14	10	7	6	4	4
	11	361	90	40	23	14	10	7	6	4	4
	12	374	94	42	23	15	10	8	6	5	4
	13	371	93	41	23	15	10	8	6	5	4
	14	381	95	42	24	15	11	8	6	5	4
	15	376	94	42	23	15	10	8	6	5	4
	16	385	97	43	24	16	11	8	6	5	4
	17	394	99	44	25	16	11	8	7	5	4
	18	401	101	45	25	16	12	9	7	5	4
	19	408	102	46	26	17	12	9	7	5	5
	20	416	104	47	26	17	12	9	7	6	5
2018	2	250	62	28	16	10	7	5	4	3	2
	3	171	43	19	11	7	5	3	3	2	2
	4	162	40	18	10	6	4	3	3	2	2
	5	161	40	18	10	6	4	3	3	2	2
	6	162	41	18	10	6	5	3	3	2	2
	7	165	41	18	10	7	5	3	3	2	2
	8	168	42	19	10	7	5	3	3	2	2
	9	171	43	19	11	7	5	3	3	2	2
	10	173	43	19	11	7	5	4	3	2	2
	11	176	44	20	11	7	5	4	3	2	2
	12	182	46	20	11	7	5	4	3	2	2
	13	181	45	20	11	7	5	4	3	2	2
	14	186	46	21	12	7	5	4	3	2	2
	15	183	46	20	11	7	5	4	3	2	2
	16	188	47	21	12	8	6	4	3	3	2
	17	192	48	22	12	8	6	4	3	3	2
	18	196	49	23	13	8	6	4	3	3	2
	19	199	50	23	13	8	6	5	4	3	2
	20	203	51	23	13	9	6	5	4	3	2

Supplemental Table S7. Number of repetitions for experiments in the design in incomplete blocks, in scenarios formed by the combinations of "i" treatments (i = 2, 3, 4, ..., 100) and "d" minimum differences between means of treatments a be detected as significant at 5% probability, by the Tukey test, expressed as a percentage of the average of the experiment (d = 5, 10, 15, ..., 50%), for the variable number of pods per plant, from plot size (Xo = 7 plants) and variation coefficient in plot size (CVXo = 15.8%) for 2017 and plot size (Xo = 5 plants) and variation coefficient in plot size (CVXo = 11.7%) for 2018, for the pea crop.

	d (%)										
	i	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**
2017	2	369	92	41	23	15	10	8	6	5	4
	3	253	63	28	16	10	7	5	4	3	3
	4	239	60	27	15	10	7	5	4	3	2
	5	238	59	26	15	10	7	5	4	3	2
	6	240	60	27	15	10	7	5	4	3	2
	7	244	61	27	15	10	7	5	4	3	2
	8	248	62	28	15	10	7	5	4	3	2
	9	252	63	28	16	10	7	5	4	3	3
	10	256	64	28	16	10	7	5	4	3	3
	11	260	65	29	16	10	7	5	4	3	3
	12	269	67	30	17	11	7	5	4	3	3
	13	267	67	30	17	11	7	5	4	3	3
	14	274	69	30	17	11	8	6	4	3	3
	15	270	68	30	17	11	8	6	4	3	3
	16	276	69	31	17	11	8	6	4	3	3
	17	283	71	31	18	11	8	6	4	3	3
	18	288	72	32	18	12	8	6	4	4	3
	19	293	73	33	18	12	8	6	5	4	3
	20	299	75	33	19	12	8	6	5	4	3
	24	302	76	34	19	12	8	6	5	4	3
	30	323	81	36	20	13	9	7	5	4	3
	40	333	83	37	21	13	9	7	5	4	3
	60	359	90	40	22	14	10	7	6	4	4
	80	374	93	42	23	15	10	8	6	5	4
	100	391	98	43	24	16	11	8	6	5	4
2018	2	204	51	23	13	8	6	4	3	3	2
	3	140	35	16	9	6	4	3	2	2	1
	4	132	33	15	8	5	4	3	2	2	1
	5	132	33	15	8	5	4	3	2	2	1
	6	133	33	15	8	5	4	3	2	2	1
	7	135	34	15	8	5	4	3	2	2	1
	8	137	34	15	9	5	4	3	2	2	1
	9	139	35	15	9	6	4	3	2	2	1
	10	142	35	16	9	6	4	3	2	2	1
	11	144	36	16	9	6	4	3	2	2	1

12	149	37	17	9	6	4	3	2	2	1
13	148	37	16	9	6	4	3	2	2	1
14	152	38	17	9	6	4	3	2	2	2
15	150	37	17	9	6	4	3	2	2	1
16	153	38	17	10	6	4	3	2	2	2
17	157	39	17	10	6	4	3	2	2	2
18	160	40	18	10	6	4	3	2	2	2
19	163	41	18	10	7	5	3	3	2	2
20	166	41	18	10	7	5	3	3	2	2
24	167	42	19	10	7	5	3	3	2	2
30	179	45	20	11	7	5	4	3	2	2
40	185	46	21	12	7	5	4	3	2	2
60	199	50	22	12	8	6	4	3	2	2
80	207	52	23	13	8	6	4	3	3	2
100	217	54	24	14	9	6	4	3	3	2

Supplemental Table S8. Number of repetitions for experiments in the design in incomplete blocks, in scenarios formed by the combinations of “i” treatments (i = 2, 3, 4, ..., 100) and “d” minimum differences between means of treatments a be detected as significant at 5% probability, by the Tukey test, expressed as a percentage of the average of the experiment (d = 5, 10, 15, ..., 50%), for the variable mass of pods per plant, from plot size (Xo = 8 plants) and variation coefficient in plot size (CVXo = 18.6%) for 2017 and plot size (Xo = 6 plants) and variation coefficient in plot size (CVXo = 13. %) for 2018, for the pea crop.

		d (%)									
	i	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**
2017	2	513	128	57	32	21	14	10	8	6	5
	3	352	88	39	22	14	10	7	5	4	4
	4	332	83	37	21	13	9	7	5	4	3
	5	331	83	37	21	13	9	7	5	4	3
	6	334	83	37	21	13	9	7	5	4	3
	7	339	85	38	21	14	9	7	5	4	3
	8	345	86	38	22	14	10	7	5	4	3
	9	350	88	39	22	14	10	7	5	4	4
	10	356	89	40	22	14	10	7	6	4	4
	11	361	90	40	23	14	10	7	6	4	4
	12	374	94	42	23	15	10	8	6	5	4
	13	371	93	41	23	15	10	8	6	5	4
	14	381	95	42	24	15	11	8	6	5	4
	15	376	94	42	23	15	10	8	6	5	4
	16	384	96	43	24	15	11	8	6	5	4
	17	393	98	44	25	16	11	8	6	5	4
	18	401	100	45	25	16	11	8	6	5	4
	19	408	102	45	26	16	11	8	6	5	4
	20	416	104	46	26	17	12	8	6	5	4

	24	420	105	47	26	17	12	9	7	5	4
	30	450	112	50	28	18	12	9	7	6	4
	40	464	116	52	29	19	13	9	7	6	5
	60	500	125	56	31	20	14	10	8	6	5
	80	520	130	58	33	21	14	11	8	6	5
	100	544	136	60	34	22	15	11	9	7	5
2018	2	250	62	28	16	10	7	5	4	3	2
	3	171	43	19	11	7	5	3	3	2	2
	4	162	40	18	10	6	4	3	3	2	2
	5	161	40	18	10	6	4	3	3	2	2
	6	162	41	18	10	6	5	3	3	2	2
	7	165	41	18	10	7	5	3	3	2	2
	8	168	42	19	10	7	5	3	3	2	2
	9	171	43	19	11	7	5	3	3	2	2
	10	173	43	19	11	7	5	4	3	2	2
	11	176	44	20	11	7	5	4	3	2	2
	12	182	46	20	11	7	5	4	3	2	2
	13	181	45	20	11	7	5	4	3	2	2
	14	186	46	21	12	7	5	4	3	2	2
	15	183	46	20	11	7	5	4	3	2	2
	16	187	47	21	12	7	5	4	3	2	2
	17	191	48	21	12	8	5	4	3	2	2
	18	195	49	22	12	8	5	4	3	2	2
	19	199	50	22	12	8	6	4	3	2	2
	20	202	51	22	13	8	6	4	3	2	2
	24	205	51	23	13	8	6	4	3	3	2
	30	219	55	24	14	9	6	4	3	3	2
	40	226	56	25	14	9	6	5	4	3	2
	60	243	61	27	15	10	7	5	4	3	2
	80	253	63	28	16	10	7	5	4	3	3
	100	265	66	29	17	11	7	5	4	3	3