Harvest Time of Some Canola (*Brassica napus* L.) Cultivar Densities in a Confounded Design

By

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B. Sc. Agric. (Agronomy), Fac. of Agric., Moshtohor, Benha Univ., 2006.

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ABSTRACT

Accounting for different sources of soil variability using blocking greatly affects precision. However, large randomized complete blocks proved unsatisfactory if researchers have not a priori knowledge of degree of complexity of soil fertility gradients and of its orientation. As a way of reducing block size, confounded designs, though have been known for half a century, researchers, however avoid their usage as a tool to control sources of soil variability. A 2-yr field study in which plant population (A) X cultivar (B) X harvest time (C) interaction was completely confounded within 9-plot incomplete blocks. The study aimed at evaluating: i) a 3^3 factorial layout with a complete confounding of the higher order interaction; ii) three different plant populations of 7.1, 9.5, and 11.9 plants m^{-2} of three canola (*Brassica napus* L.) cultivars harvested at 150, 157, and 163 DAP for seed yields and quality. This confounded model significantly fit the data of 14 dependent variables. Coefficients of multiple determination, R^2, were fairly high to high for 67% of the canola characters. They ranged from 75% to 91%, indicating that this confounded model explained the variation in the dependent variables reasonably well. The R^2 values for the other four dependent variables were from 44%-59%. Relative efficiency of the confounded design RCBD ranged from 95% to 107% for 15 canola characters; only 20% of all characters had an RE > 100%. This may imply that block size was not solely responsible for improving precision, indicating that soil fertility gradient was more complex to simply account for by decreasing block size. Incomplete blocks were laid out perpendicular to water pathways; the latter may have exerted tremendous sources of variability to contiguous plots within the same block. Achieving reasonable harvest index, seed and oil yields were obtained by planting AD201 and/or Pactol at 9.5 plants m^{-2}. There was generally no benefit to delay harvesting later than 150 DAP for either cultivar or plant density to permit timely planting of the succeeding crop.

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CONTENTS

LIST OF TABLES

Page

LIST OF FIGURES

INTRODUCTION

Field researchers always need to reach right biological decisions relying on strong and statistical basis, which in turn result in high precision. Yet, they usually encounter problems associated with soil heterogeneity that are most often difficult to detect a priori. Locally, according to the nature of field management and watering schematic patterns, problems associated with soil fertility gradients are expected to be higher. These problems are often difficult to account for by laying out experimental designs that unable to handle such heterogeneity, especially if it is of complex nature or due to many aggregated factors. Depending on the nature of the trial, there are many different statistical techniques researchers could choose to achieve their goal. The randomized complete block design (RCBD) is one of the most widely used experimental designs.

In a randomized complete block designs, a large variation between experimental units is usually expected especially within large-sized blocks depending upon the magnitude of soil gradients. Not only that but also field crops vary according to sensitivity to these gradients. Moreover, block orientation relative to sources of variability plays an important role regarding higher precision. Therefore, inflated residual errors would occur, which result in lower precision. Consequently, in such cases, there is a significance need to search for alternative statistical analyses to handle such situations.

The notion of incomplete blocks has arisen as one way that could deal with situations which lead to inefficiency of large complete blocks due to large experimental units and/or great number of treatments. In factorial experiments, confounded designs were originally developed to benefit from this principle. This is done by the sacrifice of estimating certain effect(s) of the factorial interactions as the case of higher-order interactions. This is done by confounding any interaction effect(s) within incomplete block effects. Consequently, confounded factorial designs are a technique for arranging a complete factorial experiment in incomplete blocks, where the block size is smaller than the number of all possible treatment combinations. Reasonable advantages have been attributed to using confounded designs.

The advantages come from expecting reduction in experimental errors by the use of a block which is supposedly more homogeneous, or which can be subjected to relatively more uniform crop management operations than the complete block. On the other hand, it is not possible to estimate the effects which had been confounded and in some cases there is a complexity in data analysis if number of factors is high or if missing plot data results.

The problem is, therefore, two folded. First, despite the many advantages of the confounded designs relative to the RCB designs, field researchers adopt using split plots albeit their many disadvantages. Second, they underestimate the advantages of confounded designs, thinking that they are difficult to execute and analyze, and hard to comprehend. Hence, one main objective of this study was to estimate the gain in relative efficiency, to an RCB design, of laying out a confounded 3^3 factorial designs in which a three-way interaction effect was completely confounded. This three-way interaction was initiated from a factorial combination of three canola (*Brassica napus* L.) growth-related factors.

In addition, this study also mainly aimed at exploring the potentials of canola or rapeseed as an oil crop. These potentials include its limited water requirements, salt tolerance, high seed oil quality and yield, as well as its seed meal high content of about 33% protein. This was done by studying differences between a set of cultivars in relation to varying both plant density per unit area and number of days after planting (DAP).

Cultivar, plant density and harvesting date are main factors affecting canola's productivity. Canola cultivars differ in the ability to produce branches, pods, seed weight, seed oil content, affecting so much both seed and oil yields. Productivity of canola may be acheived by a wide range of plant populations which in turn may affect branching pattern and per plant number of pods. Harvesting canola at sutiable date diminishes pod shattering which lead to yield loss, and this allows for suitable storage conditions and affect seed quality. Evaluating canola cultivars, by varying plants per unit area instead of seeding rates for three growth periods, have not been much reported so far in field studies under local conditions.

REVIEW OF LITERATURE

In this chapter I discussed two main topics. First, I emphasized the notion of the potentials of the confounded designs as a tool to improve estimating treatment precision. Generally in field experiments, experimenters often apply factorial layouts. Increasing the number of factors put much pressure on the experimenter to increase block size. In the same time, in the presence of many lurking variables that affect soil variations, precision is greatly influenced unless these variations are much controlled. Confounded designs are considered, therefore, one approach to handle the deleterious effects of such variations on estimating treatment effects. Second, I argued three key crop management factors – number of plants per unit area, cultivar, and days to harvest-- that greatly contribute to canola yields. Although the two main topics seem unrelated, both the nature of these factors and the growth habit of canola may contribute, in a way or another, to how confounded designs may be able to efficiently contribute to trial's precision.

1. Confounded Designs and precision

One aspect of experimental designs is that being statistical tools that enable experimenters controlling as much as possible lurking variables during carrying out their trials, especially the field ones. Minimizing the noise resulted from such variables, which are not under investigation by the experimenter, makes comparisons more precise. Soil variation is one major lurking variable. Controlling spatial variation among experimental units is one of the major guiding principles in deciding on an experimental design (Casler, 1999). In large yield trials, variation in soil fertility (or, more generally, yield potential) can result in substantial heterogeneity within blocks, thus, poor precision in treatment estimates (Brownieet al., 1993). In field experiments, researchers most often implement the notion of 'complete block'. They apply experimental design(s) that most rely on this notion. Field crop trials most often tests many treatments in factorial layout, but this occasionally make the complete block much greater in size. This is despite the fact that most field sites in Egypt are characterized by one more sources of soil heterogeneity. This results as consequences of field management operations such as water pathways and alleys that both separate between tiers, hand weeding, and applied fertilizer and herbicide handling, in addition to seeding and harvesting patterns.

This/these source(s) of heterogeneity, in combination with the somewhat bigger blocks, result(s), in most cases, in casting a great deal of imprecision in detecting real differences among treatment effects due to the inflation which occurs in the estimated error variance. One way to handle such heterogeneity is to consider the notion of 'incomplete block'. Unfortunately, researchers are unlikely to layout designs that depend on this principle. A set of these designs is the confounded designs. The unfamiliarity of these designs to experimenters has made Mead (1984), in a classical paper, to take the charge of clarifying how these designs are simple, efficient, and misunderstood.

i. Incomplete vs. Complete Block

The general purpose of blocking is to increase precision amongst treatment means. This can be fulfilled by ensuring that treatments are evaluated with respect to similar environmental and operational conditions within a block. Heterogeneity among plots within a block causes the estimate of a difference between two treatments to vary across blocks (Brownie et al., 1993). They further argued that the higher the heterogeneity within blocks, the greater the variation in estimates of treatment effects and this leads to poorer precision of the study.

Almost all field experiments are conducted and analyzed as block experiments—randomized blocks, split plots, lattices or similar designs. Although commonly used, randomized complete block design (RCBD) are inefficient (Casler, 1999) especially in trials involving a large number of treatments (Brownie et al., 1993). This design is appropriate in situations for which there is a known gradient among the experimental units or when the experimental units can be grouped according to some a priori pattern of variability, Casler (1999) argued. He also added that a priori variability direction, magnitude, or complexity are seldom precisely detected or even known by the field researchers. Therefore, he concluded that the effectiveness of the RCB design is limited when the field spatial variation deviates from that assumed a priori. Researchers, in practice, typically arrange RCB designs based on convenient field management especially under surface irrigation schemes. Since spatial variability can be continuous in two dimensions, RCB designs may contain considerable within-block heterogeneity that reduces their efficiency and effectiveness (Gusmão, 1986; Linet al., 1993)

Most introductory statistics text books often mention that the randomized complete block design is appropriate to layout in cases where blocks laid out perpendicularly to the direction of the fertility gradient. This argument presumes awareness of how this fertility prevails in the experimental field. It is, therefore, difficult to guarantee that blocks would exactly be perpendicular to fertility gradient. In Addition, whether plot variability within block is rather homogeneous,these two problems were the concern of Lin et al. (1993). They used 60 sets of uniformity trial soybean [Glycine max L. (Merr)] yield data to investigate soil variation in one and two directions. Results indicated that, on the average, the total sum of squares of soil variation attributable to one direction was about 39% and in two directions was about 52%. This difference of 13% reflects, in their opinion, indicates that the blocking was not perpendicular to the direction of the soil variation.

To address the second problem of plot homogeneity within block, they applied various statistical techniques such as using lattice designs, fitting constants by position effects of rows and columns, covariate analysis by plot number, and nearest neighbor analysis. They concluded that when variability within blocks is homogeneous, a randomized complete block is almost satisfactory. However, if the plots are heterogeneous then this suggests reanalyzing the data using other corrective analyses.

This RCBD is usually described as a 'single grouping' since the fundamental nature of this design is that the experimental material is divided into groups, each of which constitutes a single trial or replication (Cochran and Cox, 1957). They advised that at all stages of the experiment the objective is to keep the experimental errors within each group as small as possible. When the units are assigned to the successive groups, all units which go in the same group should be closely comparable. In addition, during the course of the experiment, as much as possible a uniform technique should be employed for all units in the same group. Any changes in technique or in other conditions that may affect the results should be made between groups, i.e. between the complete blocks not within a block. However, Brownie et al. (1993) hold that even with uniform management practices, there may still be considerable variation in soil properties among plots in a block, and, in general, the larger the required block size, the greater is the within-block heterogeneity.

To estimate the background variation in field experiments, Warren and Mendez (1982) took the problem of blocking one step further. When blocks have been laid out successfully, plots that occur in most advantageous part of the field form one block, those in the next most advantageous part form another block, etc. Blocks so arranged that match differences in plot potential, and plots within a block should guarantee the assumption that they are equal or almost equal in yield potential. When this happens, the experimental error mean square is a good estimate of 'random' or 'background' variation—if there is no treatment X block interaction. When blocks match differences in yield potential, the variation accounted for by blocks corresponds closely to the variation variously known as trend, environmental variation, positional effects, or fertility gradient.

But, when blocks have not been laid out successfully and the test site is sensitive to mismatches between blocking and yield potential, experimental error becomes inflated. It now consists of background variation plus the effects of trend that have not been taken into account by blocks. The residuals used to calculate experimental error now consist of two components: random error + undetected trend. Even though adjusted for block effects, treatment means now may be biased.

Blocks fail to account for trend when they are too large, poorly oriented, or have an unfavorable shape. Patterson and Ross (1962) examined block size effects on experimental error in 454 similar trials with small grains in England and Wales. For blocks ranging from 5 to 42 plots, average experimental error was found to increase roughly as the fourth root of the number of plots, (p), per block, (b), i.e. ($\sqrt[4]{pb^{-\square}}$). On the average, blocks with 42 plots per block had variances 1.7X those of blocks with 5 plots. Variance inflation for blocks with 35 to 42 plots was more than 2X than of blocks of 5 to 7 plots in 27% of these trials, but less than 1.2X in 41%. A similar pattern in sensitivity to block size and other influences was observed by Warren and Mendez (1981). In three trials classified as highly sensitive to choice of blocks, there were few choices that did not inflate variances seriously relative to blocks of two plots each. Variance inflation usually was greater than 2X and sometimes was as great as 4X to 6X. But in 5 trials classified as insensitive to choice of blocks, almost any block size, shape, or orientation resulted in variances similar to blocks of two. Usually variance inflation was 1.2X or less. At worst, it was 1.5X. Both studies of block choices indicate that improper blocking can produce serious variance inflation and that the occurrence of this inflation varies from one trial to another. They concluded that a block size that is effective in one trial may be very ineffective in another.

Warren and Mendez (1982) recommended that for researchers who are concerned with the practical conduct of field experiments, the key point is that there is a significant risk of conducting a trial on sites for which few block designs adequately provide for positional effects. Sites sensitive to blocking choices offer very few acceptable options for block size. They interpreted this as having limits to what we should expect to fulfill through design alone. Put another way, there will be cases when design cannot take care of positional effects, cases when other measures will be needed. To counter this hurdle, they suggested some measures. In planning experiments, (i) experimenter should use blocks to allow for variation due to operations such as planting, cultivation, recording observations, and harvesting. Even though blocks may not be able to adjust for positional effects, they should generally be adequate for what Pearce (1976, 1978, and 1980) refers to as "administrative purposes". In addition, (ii) experimenter should keep block size as small as practical. It seldom will be feasible to actually use blocks of two, but the objective should be to use block sizes that will be least likely to require corrective analyses.

Corrective analyses are performed to field experiments in which block usage --size and shape-- has not been adequate. A diagnostic method that does not rely on the suitability of a single block size or shape is therefore needed to classify field experiments on the basis of block adequacy (Warren and Mendez, 1982). Both numerical and visual methods have been proposed for this diagnostic purpose. Values of both experimental error variance and an estimate of background variation are provided for diagnostic purposes. Corrective analyses would be undertaken when the experimental error showed unacceptably high inflation. Kirk et al. (1980) suggested corrective analyses if "…..during the duration of the experiment environmental conditions, pests, or other factors caused systematic effects in the experimental units or …the fertility gradient was of a form that no experimental design could properly eliminate." Other visual indications of a need for corrective analyses include the occurrence of patches of obviously inferior growth and residual maps that suggest systematic patterns.

Hence, to increase precision in a trial, one approach is the experimenter has to consider estimating and correcting for spatial variation in yield potential due, for example, to differences among plots in soil fertility, moisture, or even pest populations. These analyses require contiguous or regularly spaced plots, arranged in a strip or rectangular grid. Precision may be improved where spatial variation is accounted for in estimation of treatment or entry means (Brownie et al, 1993). Three such types of spatial analysis are trend analysis (Casler, 1999; Casler and Undersander, 2000), the Papadakis (nearest neighbor) method (Casler, 1999) and analyses based on correlated errors models (which account for spatial variation through correlations between yields of neighboring plots (Casler and Undersander, 2000). Many methods have been proposed for achieving reductions in experimental errors. These corrective methods also approximate background variation. Early studies were conducted investigating these methods. Trend analysis methods which based mainly on polynomial regressions were applied earlier in Pearce (1978), Kirk et al. (1980), and Bowman (1990). A variety of methods based on the Papadakis technique (nearest neighbor analysis) in Pearce and Moore (1976), Pearce (1980), and Kempton and Howes (1981).

Another major approach is to reduce block size by employing an incomplete block design such as a lattice, lattice squares, and confounded designs. This norm has been so far unfamiliar to most field experimenters though it provides more precision as related to treatment comparisons, and it accommodate certain field layout obstacles other commonly used designs can not provide or at least the latter have been thought of being able to handle quite well these requirements and in fact they often are not. One of these over-used designs is the split plot designs.

ii. Critique of Split Plot Designs

A facet of experimental design related to the aversion of confounded designs is the enthusiasm for Split Plot Designs (Mead, 1984). This opinion is quite true especially among

Egyptian field researchers. This use of this designs when there are two or more factors in a study is overwhelming among field experimenters. Sometimes this use is justified on the basis of running field management practices conveniently, easier layout in the field, and the more interest in the split-plot factor(s). Yet in most cases its over-use is not justifiable since a simple factorial layout would be equally as precise as a split-plot. In many times, the main plot factor does not require larger plots; however, according to the nature of this design, a researcher forces a factor to be in the main plot where it does not need that at all. This means that the nature of the design manipulates the researcher's research hypothesis rather than (s)he does the opposite.

On the other hand, part of the experimenters' refusal of the principle of confounding that they do not completely understand the idea of confounded designs or of split plot designs. That is exactly what Mead (1984) tried to convey in his paper. He urged statisticians to try to dismiss the misunderstanding of experimenters about confounding. He tried to make it clear that: i) confounded designs provide more information than either designs with fewer factors in the same block sizes, or split plot designs; ii) the construction is not difficult; iii) the analysis for most confounded designs does not need an advanced computer software, yet a computer makes the job easier as it does for other designs; and iv) the advantages sometimes assumed for split plot experiments are at least partially misleading. Equally important, time has come for field researcher to start thinking that Split Plot Designs are not the sole statistical layout to statistically test their different research hypotheses and hence their objectives.

In factorial combinations, there is an assumption of having all treatment factors are equally treated. This argument, however, does not particularly apply to split plot designs (Mead, 1984). In split plot designs, different sizes of plot are assigned for different treatment comparisons, and this leads to changes in the information available for different effects. The more factors assigned to the consecutive splits, the greater the sizes of the main plots. This may more likely lead to reduction in the precision of comparisons between main plot factors and their interactions. Experimental areas that experience high soil heterogeneity may certainly make the situation worse for the main plot factor comparisons.

Moreover, split plot designs have several disadvantages compared with the fully randomized block designs. The level of information associated with treatment comparisons is divided into two components. Mead (1984) thinks that the division itself reduces the precision particularly for main plot comparisons. Information on split plot comparisons is improved compared with the randomized block designs, but information on main plot comparisons is reduced, and the lost precision on the latter is generally substantially greater than the gain on the former. In other words, the gain in precision in estimating the subplot effects may not compensate for the loss of precision concerning the main plot comparisons. This sacrifice may not be tolerated by the researcher and would not been experienced if the researcher had employed different design.

Although split plot designs fulfill improved information about interactions between main plot and split plot factors, Mead (1984) did not fully accept this argument. Only a subset of comparisons is improved by the use of a split plot design. This subset includes comparisons amongst levels of the split plot factor within a level of the main plot factor are improved. Equally, averaged over all main plot factor, there still improvement in the precision concerning comparisons amongst levels of the subplot factor. Quite opposite, all comparisons amongst the same split plot level in different main plot levels, those between two split plot levels in two different main plot levels, or those between mean main plot levels averaged over all split plot levels are all worse as far as precision is concerned.

Mead (1984) believes that the only proper justification to use split plot design is when practical considerations in the layout of the experiment deemed necessary. This was the original basis for the introduction of the split plot designs, and it is the only satisfactory basis. This point of view, of course, does imply that neither split plot designs are useful under certain circumstances nor are confounded designs always the sole solution to hedge against the drawbacks of split plot designs.

iii. Confounded Designs and Confounding Effects

"Indeed, I have often had the feeling that confounded experiments were viewed as a form of necromancy, suitable only for the devil or the statistician!" This how Mead (1984) sarcastically commented whenever he had suggested the use of confounded design to hold several factors, and he had found experimenters dissatisfied with the idea. When he tried to find out the reason(s) for this rejection, on the part of the experimenters, he found various misunderstandings. This is despite the fact that statisticians would regard these as a valuable, standard and under-used design, he commented. It is thought, and it has been indeed, that it needs complex computations and this requires certain computer soft wares to carry out the analyses of the data. Also the reduction in replication is thought to be a significant drawback.

In factorial experiments with many factors, to encounter the problem of a 'big' complete block which contains many treatment combinations, here comes handy the principle of a relatively 'small' or 'incomplete' block. This, of course, is to deal with the issue of soil variation in field experiments. Confounded designs mainly adopt this principle in a planned way. Mead (1984) defined confounded designs as those in which different groups of treatment combinations occur in different blocks in a certain fashion. This means that these effects are confounded with blocks, that is, the estimates are affected by block differences, as Mead explained. By implication, this means that the other effects would be 'orthogonal' with block totals (Cochran and Cox, 1957, p.184), i.e. these effects are not influenced by differences amongst blocks. Put another way, the effects may be said to be 'not' confounded with blocks, or free from block effects, or to be composed entirely of within-block comparisons. Cochran and Cox (1957) commented that the reduction in effective block size is attained by making the chosen 'confounded effect(s)' the same as one of the block comparisons, implying that there is no within-block information available about this effect in particular.

In other word, confounded effects means that two (or more) effects are confounded (aliased) if their calculated values can only be attributed to their combined effects rather than their unique individual one. Aliasing means that when the estimate of an effect also includes the influence of one or more other effects (usually high order interactions) are said to be aliased or confounded. Confounding designs naturally arise when full factorial designs have to be run in blocks and the block size is smaller than the number of different treatment combinations. For example, if the estimate of an effect D, in a four factor experiment actually, estimates D + ABC, then the main effect D is aliased with the 3-way interaction ABC. This causes no difficulty when the higher order interaction is either non-existent or insignificant. A confounding design is one where some treatment effects (main or interactions) are estimated by the same linear combination of the experimental observations as some blocking effects. In this case, the treatment effect and the blocking effect are said to be confounded. Confounding is also used as a general term to indicate that the value of a main effect estimate comes from both the main effect itself and also contamination or bias from higher order interactions.

Thus, confounding, in general, aims primarily at keeping block size smaller within each replicate, this more likely making these incomplete blocks as homogeneous as possible compared to the full or complete block should have been laid out in case of an RCB design if blocking had been laid out properly. Secondly, it aims at eliminating differences among blocks out of the experimental error sum of squares in case of factorial combinations in an RCB design. Since the nature of the 'pooled error' sum of squares in the RCB design pertains to pooled blocks by each of the main effects, as well as of the block by each of the different interactions, the part that is due to the confounded effect by block is eliminated completely and be part of the sum of squares of the incomplete blocks within replicate (blocks/reps) source of variation.

In constructing a confounded design, the classical approach has been to first select effects to be confounded (that is not capable of being assessed), the remaining effects being, by implication, unaffected by block differences. Mead (1984) adopts the alternative approach of first considering which effects are important and which should therefore be unaffected by block differences is completely general and can be applied to all factorial structures, ignoring the unimportant effects whether or not they are confounded.

The general principle of confounding though at least 50 yr old, it has rarely been applied by researchers in the field of biological science. Almost all what have so far been written about these designs does not deviate from chapters written for Experimental Design Textbooks that explains this principle on different statistical levels. (Mead, 1988; Dean and Voss, 1999; Montgomery, 2000; Hinkelmann and Kempthorne, 2005; and Oehlert, 2010). Peer-reviewed articles in the field of Agronomy or the like science do not apply this statistical technique. The illusory fears towards confounded designs explained by Mead in the early 1980s on the part of field experimenters, has still been going on. It is part of the responsibility of the statistician to unveil the assets of the confounded design.

This does not imply that confounded designs are the panacea for all experimental problems encountered in the field; however, it may provide new insights to deal with such hurdles. Either success or failure in obtaining better precision compared to an RCBD should not cast right away the possible pros and cons of these designs. These designs need be carried out repeatedly in respect to spatial and temporal variations, i.e. in space and time, taking into consideration various types of physical barriers in the field.

The advantages and disadvantages of confounding were outlined briefly in (Jaggi and Batra, available at: http://www.iasri.res.in/ebook/EB_SMAR/e-book_pdf%20files/Manual%20III/6-Confounding.pdf). Confounding reduces the experimental error by stratifying the experimental material into homogeneous subsets or subgroups. The removal of the variation among incomplete blocks within replicates results in smaller error mean square as compared with an RCBD error; thus making the comparisons among some treatment effects more precise.

On the other hand, the disadvantages are: i) in the confounding scheme, the increased precision is obtained at the cost of sacrifice of information (partial or complete) on certain relatively unimportant interactions; ii) the confounded contrasts are replicated fewer times than are the other contrasts and as such there is loss of information on them and they can be estimated with a lower degree of precision as the number of replications for them is reduced; iii) an indiscriminate use of confounding may result in complete or partial loss of information on the contrasts or the comparisons of greatest importance; iv) the algebraic calculations are usually more difficult and the statistical analysis is complex, especially when some of the units (observations) are missing; and v) a number of problems arises if the treatments interact with blocks.

Jaggi and Batra in listing the cons of confounding, they did not really justify their arguments; they just outlined their views. By studying three or more factors in factorial combinations, the researcher is usually interested in certain, out of all possible cross-classified combinations, specific effects, and even if interested in higher-order interactions it is somewhat difficult to interpret their significance. Therefore, the researcher often willingly neglect or sacrifice higher-order contrasts in favor of first-order ones at most. The question arises now if the increased precision on certain effects overrides the sacrificed information on other negligible ones. Second, this sacrifice of information is irrelevant to the experimental design type. Since the researcher decides to sacrifice some effects by applying a confounded design, hence s(he) is not much interested in regaining information on these confounded effects.

When a researcher makes a decision regarding what effects need be confounded this much depends on profound information the researcher has collected and experienced concerning the effects (s)he needs to keep way from confounding. So, this decision is supposedly not messy, yet it is fully and well scrutinized. Regarding the difficulty of calculations, it is not much different from that concerned with a factorial combination in an RCB design or in a split design. Mead (1984) argued against this issue and commented that believing in the principle of confounding itself does not necessarily require the experimenter to worry about or concern him/herself with the mathematical theory behind these designs. Maybe this difficulty arises by having missing plots or the like problems. Last, they did not mention the problems that may result once a treatment X incomplete block interaction occurs and how to be handled. Still, many questions need be resolved on the part of the statistician.

2. Plant Density, Cultivar and Harvesting Time

Generally, implementing a favorable agronomic practice such as plant density, harvest date and suitable cultivars often enhances the production of any field crop. Combining these practices especially in *Brassica napus* L. at optimal levels may further increase production and help increases net returns for producers.

i. Plant Density and Cultivars

Seed yield

Plant density is one of the important agronomic tools to modify competition amongst plants to ensure sustainable yields (Seetseng, 2008). Yield structure of *Brassica napus* L is adjustable across a wide range of plant population. Accordingly, relationships between *Brassica napus* L plant density as a number of plants per meter square and seed yield are important and very flexible. To illustrate this relationship, we can classify the plant density of *Brassica napus* L into three groups, less than 40 (lower), about 40 and more than 40 (higher densities) plant per meter square.

Firstly, under low plant densities, In Canada, Angadi et al. (2003)studied the effect of a range of uniform (5 to 80 plants m^{-2}) plant populations (season duration from May to August) on yield and yield components of canola on Swinton silt loam soil. Data indicate that there was a significance difference between low densities of (5 and 10) and high densities of (40 and 80) uniformly distributed plants m^{-2} in seed yield for *Brassica napus* L. In addition, data also imply that seed yields were similar from plant stands grown with 5 (900 kg ha^{-1}) and 10 plants m^{2} (1033 kg ha^{-1}) averaged over four trials.

Moreover, reducing uniformly distributed plant population to 5 and 10 plants m^{2} reduced seed yield relative to 40 and 80 plants m^{-2} by averaged 31 and 57%in favorable (non-water stressful) and unfavorable conditions, respectively. This is in agreement with early study by McGregor (1987), were *Brassica napus* L stands thinned (season duration approximately 97 days) to obtain populations varying from 3.6 to 200 plants m^{-2} on a dark brown Asquith fine sandy loam soil at Saskatchewan, Canada. Data show that maximum reduction in seed yield by more than 60% compared to a control of approximately 200 plants $^{-2}$ occurred at a very low densities of 3.6 plants m^{-2}either on water stressful or non-water stressful conditions.

Although McGregor (1987)justified that the seed yield dropped off rapidly below approximately 8 plants m^{-2}because there is no potential for compensation due to non-appreciable interplant competition, but data imply significant increasing in yield components such as pod and branches numbers per plant, in addition to increasing in seeds per pod and seed weight in some instances especially at these lowest densities. Thus, sharp seed yield reduction at these lowest densities may have occurred due to plant number per square meter was insufficient for fully yield compensation.

Concerning the moderate plant density of about 40 plant m^{-2}, Angadi et al., (2003),concluded that reducing population by 50% from 80 to 40 uniformly distributed plants m^{-2} had no effect on seed yield, whether under non water stressful or stressful conditions. This is in agreement with McGregor, (1987), as I depicted from his data that seed yields were similar from plant stands grown with 86.3 and 40 plants m^{-2} but only under non water stressful conditions. He generally concluded that plant density could be reduced to as little as 40 plants m^{-2} with less than 20% yield loss compared to a control of approximately 200 plants m^{-2} and more than 20% if the plant populations were reduced to below 40 plants m^{-2}.However, these results indicated the importance of environmental conditions in determination of the optimum population.

Further, from 2002 to 2004 at 5 sites-years Chen et al (2005), using 11, 32, 65 and 97 plant $m^{-2}$and two *Brassica napus* L. cultivars found that seeds per square meter had significant influences on canola yield at both locations, and these influences also differed by years and locations. Under favorable conditions, the canola yield increased greatly when the seeding rate increased significantly from 11 to 32 seeds m^{-2}. They also found that a seeding rate of 32 to 65 seeds m^{-2} was sufficient to produce optimum yields. Shrief (1989) studied the effect of three plant densities as 30, 60 and 90 plants m^{-2} on yield and yield components of four *Brassica napus* L genotypes Callypsso, Semu 2080, Semu DNK203/84, Semu 304 at two sites from 1986 to 1987 on a sandy loam soil, Germany. He indicated that seed yield per plot was estimated in 1987 season only because bad weather in 1986 season (long drought period followed by extensive rainfall) which caused regrowth of plants during maturity; therefore, it was impossible to determine the plot yield. From data, plant density had no significance effect on seed yield which averaged 193 kg fad^{-1} over four genotypes.

As a result of poor seeding and unfavorable growth conditions including inadequate or excessive soil moisture, soil crusting, low temperature, seeding equipment, late spring frost , hail damage, fall or early spring seeding and whether disease or insect infestations, it could be better to use more than 40 plant m^{-2} for expressing these bad conditions and achieve appreciable yields. In addition, earlier maturity by 12 days was observed at higher densities of 83.3 compared to 3.6 plant m^{-2} inferred from data by McGregor (1987). On the other hand, some studies showed that the proportional high densities could be sometimes considered agronomically inappropriate because of excessive intraspecific competition. In addition, higher densities may lead to lodging and subsequent greater susceptibility to plant diseases.

Consequently, using higher plant densities according to previous conditions also need to determine the optimum density.

Under high plant densities, Dosdall et al. (1996)conducted a field experiment during 1991 and 1992 in Alberta, Canada under substantial root maggot *Delia spp* infestations. According to my calculations, seed yield ranged approximately from 696 kg ha^{-1} at plant density of 763.2 plants m^{-2} reaching a maximum of 919 kg ha^{-1} at plant density of 433.6 plants m^{-2}) for *Brassica napus* L. Although there was more than 200kg ha^{-1} difference between the two previous treatments, densities of 95.2to 763.2 plants m^{-2} had not significant effect on seed yield. This appreciable difference in magnitude without significance was not illustrated by them, but it may be occurred due to weakness of the power test. In another experiment, Dosdall et al. (1998) conducted a field experiment at two sites during 1995 and 1996, for *Brassica napus* L under conventional tillage and substantial root maggot infestations in Alberta, Canada. Data show that the actually obtained densities 125.2, 185.1, and 248 plants m^{-2} had not significant effect on seed yield that ranged approximately from 1835 kg ha^{-1} at plant density of 248 plants m^{-2} to 1895 kg ha^{-1} at plant density of 125 plants m^{-2} where means averaged over three row spacing (10, 20 and 30 cm).

Although above studies had indicated that *Brassica napus* L could be established by about 40 plant m^{-2}without reduction in seed yield especially under good growing season, Angadi et al. (2003) and Chen et al. (2005) reported Thomas (1984)who indicated that a wide range of plant densities of 80 to 180 m^{-2} have been recommended for canola production in the Canadian prairies. This high seeding rate for canola production in Canada recommended basically because of bad soil and weather conditions such as poor seeding (in some regions, the emergence exhibit less than 50% under field conditions) and unfavorable growth conditions including inadequate or excessive soil moisture, soil crusting, low temperature, late spring frost , hail damage, fall or early spring seeding and whether disease or insect infestations. Similarly, in Egypt, this recommendation of high plant densities has been approximately recommended. For instance, in Egypt under high plant densities during 2002 and 2003 (with a long growing season about 160 days), Taha (2007) planted *Brassica napus* L cultivar Serw4 using 1, 2, and 3 kg fad^{-1} on a clay loam soil. These seeding rates theoretically are about equivalent to 76, 152 and 229 plant m^{-2}, respectively and did not differ for seed yield which ranged from 1036 to 1050 kg fad^{-1}. Consequently, it may be useful to test another lower plant density at the optimum level especially in the regions which have more stable and favorable soil and weather conditions compared of those in Canadian prairies.

Determining the optimum plant density depending on number of actual plants per square meter is more precise than seeding rate based on weight as we will illustrate later. As we indicated before that Taha (2007) used seeding rates based on weight, as well as Morrison et al.(1990) in Manitoba, Canada, who observed that the highest yields of Westar cultivar were achieved with 1.5 and 3.0 kg ha^{-1} compared to the seeding rates of 6.0 and 12.0 kg ha^{-1} for *Brassica napus* L for 4site-years, without taken in his account the number of plants per square meter.

On the other hand, in a two different studies by Johnson and Hanson (2003); Lamb and Johnson (2004)seeding rate was based on pure live seed count rather than weight and Johnson and Hanson (2003) have a justification for that. Their justification depended on studies which included more than one cultivar, so the seeding rates based on weight could represent a different number of sown seeds because cultivars and cultivar seed sources can exhibit distinctly different seed weights. This was acknowledged by Morrison et al. (1990a) who did not rather conducted analysis across years in their study because different seed sources between years caused different initial plant stands when seeding rate was based on weight (Johnson and Hanson, 2003).

In addition to the importance of pure live seed count, Christensen and Drabble (1984) in Alberta, Canada, counted the number of plants per meter square 2 weeks after emergence and again at harvest. From their data, mean number of plants per square meter was 159 after emergence and 113 plants m^{-2}(averaged over two seeding rates, three row-spacing and two years) at harvest. This will appear greatly whether especially at poor seeding conditions, unfavorable growth conditions or even using bad vigor cultivars, so we can expect a variation between number of plants per unit area in the beginning (targeted population) and the end of the season (actual population) leading to lower seed yields. Therefore, it is useful to base on pure live seed count rather than weight and correspondingly on actual rather than targeted densities with selecting suitable cultivars which lead to good establishment.

Therefore to achieve appreciable yield, not only optimum plant density but also suitable canola cultivars must be selected. The suitable cultivars must have high seed yield and good establishment under field conditions. Consequently, Harker et al. (2003) studied the effect of three seeding rates targeted at planting as 100, 150 and 200 seeds m^{-2} on yield and yield components of two canola *Brassica napus* L cultivars In Vigor 2153 (hybrid) and Exceed (open-pollinated) at two sites from 1998 to 2000 on a clay loam soil, Alberta, Canada. Their experience at these sites suggested that only 50% emergence occurs under field conditions. Therefore, they used cultivars that have > 90% percentage germination. Actual densities in this study were obtained as approximately 50, 75 and 95 plants m^{-2}averaged across sites for targeted plant densities of 100, 150 and 200 seeds m^{-2}, respectively. They found that at equal targeted plant density, the hybrid cultivar had greater seedling density (8 plants m^{-2} higher) and seed yield (22% higher) when compared with the open-pollinated cultivar. So it has been shown that selection of canola cultivars greatly determines the number of plants per unit area that actually emerges under especially bad field conditions, therefore it could affect strongly the seed yield. They also found that actual plant density of 50 plant m^{-2} compared with higher plant densities of 75 and 95 reduced yields of both cultivars (hybrid and open-pollinated) by 7% at all, but it should be notice that data indicates that interaction between cultivar and seeding rate had no significant effect on seed yield.

Similarly, Chen et al.'s data (2005) indicated that the effect of interaction between plant density (11 to 97 plants m^{-2}) and cultivar was not significant for seed yield in 5 site-years study. However, overall, they found that cultivar DK223 yielded significantly 48 kg ha^{-1} greater than Hyola357 at first site in the three years of study with no significant difference at the second site. Same results were also obtained by Shrief (1989) as plant density (30 to 90 plants m^{-2}) × cultivar interactions had no significance effect on seed yield while differences among 4 cultivars in 1987 season were significant for seed yield which ranged from 192 to 252 kg fad^{-1} for Semu DNK203/84 and Callypsso, respectively.

In a study conducted by Johnson and Hanson (2003) using approximately 160 pure live seed per square meter at two sites on fine-loamy and fine silty soils, in Canada. However, they did focus on row spacing and some *Brassica napus* L cultivars, Hyola 401 (hybrid), Hudson and Limagrain 3295 (open-pollinated), for increasing seed yield. By inspecting data, a hybrid yielded averaged 21.5 to 27% more than the two open-pollinated cultivars, respectively, which produced similar yield. Similarly, in the same region at two sites from 1999 to 2000, Lamb and Johnson (2004) using plant density of 148.2 pure live seed m^{-2} found that Hyola 401 (hybrid) yielded greater than Hudson (open-pollinated) by 26% averaged across seed size categories, seeding depths and environments. On the other hand, in Turkey, from 1994 to 1995 on a loamy soil, Ozer (2003) found that seed yield was averaged 1052 kg/ha^{-1} without significant differences of two *Brassica napus* L cultivars Tower and Lirawell.

Results found by Taha (2001) in Egypt were consistent with findings obtained by (Harker et al., 2003;Johnson and Hanson, 2003;Lamb and Johnson, 2004).He planted, during 1998 and 1999,15 *Brassica napus* L genotypes with seeding rate 3 kg fad^{-1} on a clay loam soil. Combined data indicate that genotypes varied significantly in seed yield per faddan overall four nitrogen levels and seed yield of AD201was higher than Pactol by approximately 9.9%. Generally, seed yields ranged from 717 to 906 kg fad^{-1} for (Canola 103) and (hybrid L5), respectively. In the same research by Chen et al. (2005) but another experiment, they tested 17 canola genotypes including 9 commercial cultivars and 8 breeding lines which were established using 65 plants m^{-2} in 2004. Data show that seed yield was significantly affected by genotypes and ranged from 880 to 1350 kg ha^{-1} in the first location and from 1800 to 2610 in the second.

Plant height

By inspecting data from Shrief (1989), plant height was affected significantly by cultivars and plant density in two seasons of study. Maximum plant heights were 106 and 127 cm under unfavorable and favorable conditions respectively; for Callypsso and Semu DNK203/84, respectively. Data showed that under favorable conditions, plant height was inversely proportional with plant density and the differences among plant densities were around 4 cm, while the differences were less than

1 cm under unfavorable conditions. Maximum plant heights were 101 and 97 cm under unfavorable and favorable conditions respectively; for densities of 90 and 30 plants m^{-2}, respectively. Plant density × cultivar interaction was significant for plant height only in the first season; tallest (109 cm) and shortest (96 cm) plant heights were observed at 30 plants m^{-2} for Callypsso and Semu 2080, respectively.

The same findings were obtained by Johnson and Hanson (2003) as they found that cultivars exhibited different plant height as (Hudson, open-pollinated), (Hyola 401, hybrid) and (LG3295, open-pollinated) were 104.5, 107 and 112 cm respectively where means averaged over two row spacing. Similarly, for Hudson and Hyola 401 cultivars, Lamb and Johnson (2004) found across environments, the same plant height of both(117 vs 116), respectively, at plant density of 148.2 pure live seed m^{-2}. Ozer (2003) was in agreement with Johnson and Hanson (2003) and found differences between cultivars in plant height. Plant heights for cultivars Tower and Lirawell were 101 and 118 cm, respectively. Also, Harker et al. (2003) found that InVigor 2153 (hybrid) is usually at least 15 cm taller than Exceed (open-pollinated).

In confirmation with previous findings, Taha, (2001) found that 15 genotypes differed significantly in plant height. Combined data showed that plant heights ranged from 140 in (Pactol) to 157 cm in (Canola 102) (means averaged over 4 N levels). Cultivar AD201 recorded 153 cm which did not differ from that of Canola 102 but differed significantly from Pactol.

Primary, secondary and total branches

Seed yield is a function of the number of plants per unit area, pods per plant, seeds per pod, and seed weight. Formation of pods always occurs on the main shoot, new inflorescences from the axils of the leaves (primary branches), and by secondary development of inflorescences on the existing inflorescences (secondary branches). In canola, number of primary and secondary branches or both as total branches, is greatly dependent on plant density.

For instance, by inspecting data from Shrief (1989), Data showed that number of branches per plant differed significantly by plant density in the two seasons. From his data, number of branches per plant was inversely proportional to plant density ranging from 30 to 90 plants m^{-2} in the two seasons; it linearly decreased from 5 to reach 3 branches per plant. Also data showed that number of branches per plant did not differ significantly by plant density × cultivar interaction in the two seasons.

Similarly, by inferring data from Taha (2007), number of both the primary, secondary and total branches per plant was inversely proportional to plant densities ranging from 76 to 229 plant m^{-2}; it linearly decreased from 7.84 to reach 4.8; 1.86 to 0.01; and 9.70 to 4.81 for primary, secondary and total branches, respectively, averaged over seasons. This confirms with McGregor (1987) who shows that the number of total branches per plant increased significantly by fourfold (4:1) or more than in higher densities (14.8 in lower: 3.3 in higher densities) where means of total branches per plant was averaged for low densities of 3.6, 7.2 and 21.7 plant m^{-2} and high densities of 144, 186 and 200 plant m^{-2}, respectively across years for *Brassica napus* L. It appears greatly again the inverse relationship between the number of total branches and plant density within the lowest densities. Number of total branches was linearly decreased from 22 to 8 branches (averaged over years) at these lowest densities.

Concerning the effect of cultivars on the number of total branches per plant, Ozer (2003) found that number of total branches per plant averaged 4.7 without significant differences between Tower and Lirawell cultivars. On contrary, Shrief's data (1989) showed that number of branches per plant differed significantly among 4 cultivars in the first season only and the variability in number of branches per plant among cultivars was around 2 branches.

Pods per plant

Yield compensation in canola could occur by producing more seeds on the main shoot, primary branches, and secondary branches (Angadi et al. 2003). Accordingly, the number of pods per plant is considered the most important factor responsible for yield compensation.

By inspecting data from McGregor (1987), plant density also strongly influenced the number of pods per plant within the domain of low plant density (3.6, 7.2, 21.7 plant m^{-2}). Pod number was inversely proportional to this plant densities; it linearly increased significantly from 85 to reach 214 pods. In general, at lower densities, pod number per plant increased significantly by fivefold (5:1) or more than in higher densities

(153 in lower : 28 pods plant^{-1} in higher densities), means was averaged for low densities of 3.6, 7.2 and 21.7 plant m^{-2} and high densities of 144, 186 and 200 plant m^{-2}, respectively across years.

These results are consistent with those obtained by (Morrison et al. 1990) as pod number was also significant linearly increased with decreased seeding rates from 12 to 1.5 kg ha^{-1} for 4site-years. Angadi et al., 2003 also found that the pod number was significantly linearly increased from 95 to reach 430 pods (averaged across two years under favorable conditions) with decreased uniformly plant density from 80 to 5 plant m^{-2}. It should be noticed that there was no significant difference between lower plant density of 5 and 10 plants m^{-2} on number of pods plant^{-1} under favorable conditions. In addition environmental conditions can play a significant role for increasing the pod number per plant. For instance reducing plant population from 80 to 40 plant m^{-2} under favorable conditions increased the number of pods per plant by 78% compared to unfavorable conditions by averaged 32%. Within high densities, from Taha (2007), again there was an inverse linear relationship between number of pods per plant and plant density. Data show that the number of pods per plant increased from 177 reach to 331 pods with reducing plant density from 229 to 76 plant m^{-2}. Similarly, by inspecting data from Shrief (1989), pod number per plant was significantly linearly increased and reached two fold with decreased plant density from 90 to 30 plants m^{-2} in the two seasons. Also data imply that number of pods per plant did not differ significantly by plant density × cultivar interaction in the two seasons.

Concerning the relationship between the cultivars and number of pods per plant, data from Shrief (1989) showed that the significant variability in number of pods per plant among 4 cultivars occurred in the second season only and was around 57 pods; maximum number of pods per plant (170 pods) was observed for Semu DNK203/84 cultivar. Taha (2001) showed from combined analysis that the 15genotypes differed significantly in number of pods per plant and ranged 89.5 in Pactol variety to 119.6 pods in Semu 304 genotype over all four nitrogen levels. In addition, combined data showed that Pactol variety possessed the lowest number of pods per plant and Semu 304 exhibited the highest mean of pods per plant without significant differences from AD201 genotype (110 pods plant^{-1}). On the other side, Ozer (2003) found that number of pods per plant averaged 172 pods without significant differences from Tower and Lirawell cultivars.

Seeds per pod, 1000 seed weight and seed weight per plant

In spite of the previous studies that showed that the number of pods per plant was strongly influenced by the plant density, the number of seeds per pod and seed weight was not (Huhn and Schuster 1975; Clarke and Simpson 1978a; Clarke et al. 1978)as reported by McGregor (1987). This is in agreement by Angadi et al. (2003), who show that seeds per pod and thousand seed weight were not affected significantly by a uniform plant population ranged from 5 to 80 plant m^{-2}. Also by inspecting data, number of seeds per pod and thousand seed weight were not affected significantly either under favorable or stressful conditions, 23.64 seeds and 2.92 g, respectively. Also Morrison et al. (1990) showed that the thousand seed weight was not affected significantly by seeding rates ranged from 1.5 to 12 kg ha^{-1} for 4site-years.

On the contrary of these results, data showed from Shrief(1989),significant differences among cultivars or among plant densities for the number of seeds per pod and thousand seed weight in the two seasons of study. The variability in number of seeds per pod and thousand seed weight was around 3 seeds and 0.5 to 1 g respectively, within either cultivars or plant densities. Data also showed that plant density × cultivar interactions was significant for number of seeds per pod and thousand seed weight, only in first and second season, respectively. Highest number of seeds per pod (21 seed) was observed at 60 plants m^{-2} for Semu 304, while the lowest number (14 seed) was observed at 90 plants m^{-2} for Semu DNK203/84. The heaviest thousand seed weight (4 g) was observed at 60 plants m^{-2} for Callypsso, while the lightest (2.5 g) was observed at 30 plants m^{-2} for Semu DNK203/84.

Results of Shrief (1989) are in confirm with McGregor's (1987) who found that number of seeds per pod and thousand seed weight increased in some instances with reduced plant density. Data imply that number of seeds per pod and the thousand seed weight averaged 19.4 seeds and 3.9 g respectively at densities of 3.6 to 21.7 plant m^{-2} and averaged 17 seeds and

3.7 g respectively at densities of 144 to 200 plant m^{-2} across years.

Similarly, Taha (2007) also found that number of seeds per pod and thousand seed weight were significantly reduced with increased plant density from 76 to 229 plants m^{-2} in combined results. Number of seeds per pod and thousand seed weight were decreased from 17.40 to 15.56 seeds and from 3.18 to 3.02 g, respectively. Significant reduction in seed yield per plant coincided with this last result accompanying with the result we indicated before as pod number per plant was reduced from 331 to 177 pods with increasing plant density. Combined data from Taha (2007) indicate that seed yield per plant reduced from 18 to 8.3 g plant^{-1} in Serw4 variety with increasing plant density from 1 to 3 kg fad^{-1} (theoretically 76 to 229 plants m^{-2}).Also data showed from Shrief (1989) that the differences among plant densities ranged from 30 to 90 plants m^{-2} were significant for the seed yield per plant in the two seasons of study. Under favorable and unfavorable conditions, seed yield per plant was inversely proportional to plant density and ranged from 2 g plant^{-1} to reach maximum of 12 g plant^{-1} at unfavorable and favorable conditions, respectively. The effect of plant density × cultivar interaction was not significant for seed yield per plant in two seasons of study.

Concerning the effect of cultivars on these characters, Ozer (2003) found that number of seeds per pod and thousand seed weight averaged 24.5 seeds and 4.1 g, respectively without significant differences between Tower and Lirawell cultivars. Although, Harker et al. (2003) did not take the number of seeds per pod in their account, but they have added that interaction effect of both plant density and cultivar did not differ significantly for the thousand seed weight. By inspecting data, averaged over three canola growth stages 2, 4, 6 leaf, the three actual plant densities of 50, 75 and 95 plant m^{-2} had no significant effect on the thousand seed weight for both a hybrid and open-pollinated cultivars across 5 site – year environments. In addition, they found that the hybrid had significantly 9% greater thousand seed weight than open-pollinated cultivar at all sites. In general, the minimum thousand seed weight was 2.90 g and the maximum was 3.40 g.

On the contrary of results by (Ozer, 2003) and similar to (Harker et al., 2003), Taha (2001) found that fifteen genotypes differed significantly in number of seeds per pod and the thousand seed weight. Combined data showed that number of seeds per pod ranged from 18.40 in (Semu 304) to 24.8 seeds in (Pactol) variety which showed significant differences from that of (AD201) of 19.2 seeds (means averaged over 4 N levels). The thousand seed weight ranged from 3.02 g in (Pactol) to 3.62 g in (AD201). This last result accompanying with the result we had indicated before as pod number per plant was 89.5 and 110 pods plant^{-1} for these varieties respectively, could explain the significant reduction in the seed yield per plant for them as 6.30 and 7.57 g plant^{-1}, respectively. In addition, Taha (2001) found that seed yield per plant for the 15 genotypes ranged from 6.30 in (Pactol) to 7.63 g plant^{-1} in (hybrid L5) (means averaged over 4 N levels).Similarly, data showed from Shrief (1989) that differences among 4 cultivars were significant only in second season for the seed yield per plant which ranged from 7 to 9 g plant^{-1}.

Straw yield and harvest index

By inspecting data from Angadi (2003), under favorable conditions, the effect of plant density from 5 to 80 plant m^{-2} had no significant difference on biomass which averaged 4971 kg ha^{-1} over two years. In the same time, as previously indicated in the same research that reducing uniformly distributed plant population to 5 and 10 plants m^{-2} reduced seed yield by 31% of 40 and 80 plants m^{-2} under favorable conditions. As a result of accompanying the same biomass (seed plus straw yields) with different seed yield at varied plant densities, consequently, this is highly indicates that straw yield compensation occurred at these low densities by producing more primary or secondary branches. Although Angadi (2003) did not directly indicate to the straw yield as values per hectare but, we can get it easily by subtracting the seed yield from the biomass values. According to the calculations, under favorable growing seasons, the straw yield for uniformly distributed population of 5 and 10 plants m^{-2} averaged 5024 kg ha^{-1} while averaged 4960 at 40 and 80 plant m^{-2} averaged over two seasons. Generally, under favorable conditions, straw yield averaged 4570 to 5352 kg ha^{-1} over two years.

According to above justification as we indicated before, by inferring data from Angadi (2003), under favorable conditions, the effect of plant density from 5 to 80 plant m^{-2} had no significant difference on the harvest index which exhibited

29.6% average over two years. On the contrary, Shrief's data (1989) showed that differences among either plant densities (30 to 90 plants m^{-2}) or among 4 cultivars were significant for the harvest index (HI) in the two seasons of study. From data under unfavorable conditions, HI was inversely proportional with plant density and ranged from 20 to 25% while it was inconsistent under favorable conditions and ranged from 38% at 30 plants m^{-2} to reach maximum (40%) at 60 plants m^{-2}.Plant density × cultivar interactions was significant for HI only in the second season where the highest HI (40%) was observed at 60 plants m^{-2} for Callypsso and Semu 304, while the lowest (30%) was observed at 90 plants m^{-2} for Semu 2080. It should be emphasize that maximum HI (39%) was observed for Callypsso in the second season which had a favorable growth condition such as temperature, sunshine hours, adequate rainfed; versus (27 %) for Semu DNK203/84 in the first season as represents bad growth conditions.

Oil % and oil yield

Earlier we indicated that to achieve appreciable yield, not only optimum plant density but also suitable canola cultivars must be selected which have a high seed yield and good establishment under field conditions. Also selection of cultivars that have high seed oil content is preferable. The variability of the oil % is highly dependent on the genetic constituents of the genotypes. For instance, Ozer (2003) found that cultivars differed significantly in oil % and were 39.7 and 40.4 % for Tower and Lirawell, respectively. The oil yields differed according to the differences in seed yield and oil % and were calculated as 173 and 180 kg fad^{-1} for Tower and Lirawell, respectively. Taha (2001) found also a significant effect of 15 genotypes on seed oil content in a combined analysis. Oil % varied from 35.2 (L3 hybrid genotype) to 37.6 % in Pactol. In addition, data showed that AD201 differs significantly from Pactol and recorded 36.2%. The oil yield ranged from 263 to 324 kg fad^{-1} for (Canola 103) and (hybrid L5), respectively. In addition, the oil yields were 279 and 301 kg fad^{-1} for AD201 and Pactol, respectively. By inspecting data of Chen et al. (2005), the oil % differed significantly among 17 cultivars and ranged from 37.7% to 42.5 % in the first location and from 42.8 to 46.0 % in the other. The oil yield ranged from 154 to 214; 330 to 471 kg fad^{-1} for first and second site, respectively. Harker et al. (2003) found that the hybrid (InVigor 2153) had significantly less oil concentration averaged as 42.6 % than open-pollinated cultivar (Exceed) as 43.9 % averaged across 5 site-years. However, they reported that the cultivar seed oil content of this magnitude has little or no agronomic or economic significance. From their data, the oil yields averaged 375 and 450 kg fad^{-1} for Exceed and InVigor 2153, respectively, averaged over plant densities, time of weed removal and across 5 site-years. Similar results were observed from Shrief' data(1989), as oil % differed significantly among 4 genotypes and ranged from 40 to 42 % averaged over two seasons for Semu DNK203/84 and Callypsso, respectively. Data showed that oil yields ranged from 77 to 105 kg ha^{-1} for the second season.

On the other hand, Lamb and Johnson (2004)found non significant effect of genotypes on oil %at plant density of 148.2 pure live seed m^{-2}. According to our calculations, the oil % averaged 36.5% while the oil yields averaged 227 and 307 kg fad^{-1} for Hudson and Hyola 401, respectively. Also, Johnson and Hanson (2003) found the same results at plant density of 160 pure live seed m^{-2}.By inspecting data, oil % averaged 38.6% while the oil yields averaged 280, 295 and 385 kg fad^{-1} for Limagrain 3295, Hudson and Hyola 401, respectively.

Agronomic practices such as plant density has a limited effect on oil % and environmental conditions may affect this character more than this practice. For example, Dosdall et al. (1996) found that varied densities of 95.2 to 763.2 plants m^{-2} had no significant effect on oil %, according to data, the oil % and oil yields averaged 44% and 149 kg fad^{-1} over densities, respectively. Similarly, Harker et al. (2003) observed that actual densities of 50, 75 and 95 plants m^{-2}, across two sites, had no effect on seed oil content for both cultivars InVigor 2153 and Exceed across sites. The same was observed by Taha (2007) , as he found from combined analysis that oil % of (Serw4) ranged from 36.61 to 37.11%, was not affected significantly by seeding rates of approximately 76, 152, and 229plants m^{-2}. However, his data indicates a slight significant increase at 229 plants m^{-2}and the oil yield averaged 384 kg fad^{-1}.Also, Morrison et al. (1990) observed that there was no consistent effect of seeding rates ranging from 1.5 to 12.0 kg ha^{-1} on the oil % for Westar cultivar for 4site-years, and they indicated that the greater differences in oil % existed among environments more than among seeding rates.

On the other hand, in another experiment by Chen et al (2005), by inspecting data, although oil % was not affected significantly by either cultivar (DK223 and Hyola375) or its interaction with plant density (11 to 97 plants m^{-2}), oil % responded to plant density and the responses differed among years and locations. For example, they found, at the first location oil % tended to decrease with increased plant densities in all 3 yr, but the magnitude of the difference was small (<1.5 %). In the other location, oil % decreased significantly by 1.8 % when plant density increased from 11 to 97 plant m^{-2} in the 1st year, but it did not change significantly with increased these densities in the second year.

The variability in precipitation and temperature across years and locations affected previous results and indicated to the role of environmental conditions which could affect the oil %. This role was observed in researches conducted by (Shrief, 1989; Morrison et al., 1990; Dosdall, 1996; Johnson and Hanson, 2003) and contrasted with (Lamb and Johnson, 2004).

Similar findings which obtained by Chen et al (2005) was observed for Shrief (1989) as data showed that effect of either plant density (30 to 90 plants m^{-2}) or plant density × cultivar interactions was significant for oil % only in the first season where the highest oil % (43%) was recorded at 60 or 90 plants m^{-2} for Callypsso, while the lowest oil % (40%) was recorded at 90 plants m^{-2} for Semu DNK203/84. For all three plant densities in the first season, oil % was around 42% averaged over 4 cultivars and 2 row spacings.

ii. Harvesting time

Stage of seed development at harvest influences both canola yield and seed quality. Harvesting too early may result in poor seed quality (viability and vigor), so bad stand establishment and yield are expected, whereas harvesting too late may result in pod shattering and reduced seed yield. Elias and Copeland (2001), during 1989 to 1990 on a clay loam soil at East Lansing, MI, planted four winter and two spring cultivars at a rate of 5.6 kg ha^{-1}. This is to determine the early harvest as physiological maturity (PM)[1] and the late harvest as harvest maturity (HM)[2]using physiological characteristics as seed moisture content (SMC).

Data of Elias and Copeland (2001) showed that SMC was not affected significantly by either cultivar or interaction between cultivar and seed age (time by weeks after pod formation), but it was affected significantly by seed age. Seed moisture content (SMC) of all cultivars decreased gradually from initial seed formation to the HM for either winter or spring cultivars. In their study, at maximum seed dry weight canola cultivars attained PM (six weeks after pod formation for spring and winter cultivars) when seed moisture content ranged from

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[1] PM in the growth key of Harper and BerkenKamp (1975), when plants reach ripening in Stage 5.3.

[2] HM in the growth key of Harper and BerkenKamp (1975), when plants reach ripening in Stage 5.5.

20.3 to 36 %, while these cultivars attained HM (7 to 8 weeks after pod formation for spring and winter cultivars, respectively) when seed moisture content dropped to near 10 to 12 %.They concluded that canola can be harvested too early at PM about 2 weeks before reaching HM without affecting yield.

Although seed quality is not at the highest level, by harvesting at PM compared to HM, it may be advisable to harvest the crop at PM than at HM. This is if the crop is excessively weedy or to avoid excessive bird damage or unfavorable weather conditions during late maturation and harvest and also to permit timely planting of the next crop. Elias and Copeland, (2001) reported that harvesting too late at HM may result in pod shattering and reduced seed yield. Fully mature pods of oilseed rape (*Brassica napus* L.) are extremely sensitive to opening, resulting in seed loss (Child et al., 2003). This can take place prior to harvest due to disturbance of the canopy by wind or during harvesting as the combine harvester machinery moves through the crop. Typical losses vary between 8% and 12% of the potential yield, but reductions of up to 50% were observed in seasons when weather conditions were poor prior to and during harvest. Moreover, Pahkala and Sankari, (2001) reported that the shed seeds may remain viable during several years and germinate to produce volunteer plants, which represent weeds in the following crops. Child et al. (1998) also reported that pod shattering is a particular problem in oilseed rape (*Brassica napus* L.) because of marked tendency of fully mature pods to open. Average annual losses of about 20%, represent a production efficiency that is far less than in any other major arable crop.

Child et al., 1998 reported that there is little variation in the susceptibility of current cultivars to pod shatter and conventional breeding has so far been unable to produce new cultivars which are more resistant to opening. From here, harvesting the crop at PM may help avoid pod shattering during late maturation at HM thereby improve production efficiency. In general, a reduction in the sensitivity of pods to opening would increase the proportion of the yield recovered by the combine harvester and thereby improve production efficiency (Child et al., 2003). Although canola can be harvested at HM with expected pod shatter, it is better to leave the crop at this stage for maximum potential quality (i.e., germination and vigor) if the purpose of planting is for seed (e.g., foundation or certified seed), in addition to better threshing and storability because of suitable moisture content of both pods and seeds (Elias and Copeland, 2001). So we can say briefly, that maximizing each of production and seed quality thereby good establishment of canopies and storability are highly dependent on the harvest date.

Although, Taha (2007) doesn't take in his account the physiological characteristics such as SMC but he added the effect of three harvest dates on seed yield and its componentsto permit timely planting of the next crop in crop rotation (e.g., *Gossypium barbadesnse* L. or *Glycine max* (L) Merr*)*.Three harvesting dates were practiced; the first one was at physiological maturity when most of pods on the main branch turned to yellow color (according to Elias and Copeland, 2001), approximately after 146 days from planting on 27 November. Then 2nd and 3rd harvesting dates were applied at one and two weeks later, respectively. Taha (2007) found, from combined analysis, that seed yield and the following five components were not affected significantly by harvesting dates. According to our calculations, the seed yield, oil %, oil fad^{-1}, seed yield plant^{-1}, seeds pod^{-1} and the thousand seed weight were averaged 905 kg fad^{-1}, 37.57 %, 340 kg fad^{-1}, 14.43 g plant^{-1},14.8 seeds pod^{-1} and 3.10 g averaged over three harvesting dates for Serw4 variety. The non-significant effect of harvesting date treatments could be occurred due to these characters being already developed before the too early harvesting date treatments.

MATERIALS AND METHODS

A 2-year field experiment was conducted at the Agricultural Research and Experimental Center, Faculty of Agriculture, Moshtohor, Kalubia, Benha University, Egypt, during 2007 and 2008 on a clay loam soil. Before the onset of the field trial, the experimental area was ploughed to a depth of 0.25 m. The plot size was 3.5-m × 3-m of five 0.70-m ridges. A 2-ridge inter-plot distance was left.

Three canola (*Brassica napus* L.) cultivars, AD201, Pactol and Serw4 (hereafter named Factor B) were hand-seeded on 27 November and 1 December during 2007 and 2008, respectively. AD201 cv. was obtained from the National Research Center, Egypt, Pactol from Oil Crops Council, Ministry of Agriculture, and Serw4 from El-Serw Experimental Station.

Three plants densities (hereafter named Factor A) were targeted at planting as 7.1, 9.5 and 11.9 plants m^{-2}. These plant densities were established by seeding at 40, 30 and 24 cm hills for the three densities, respectively. At the beginning of the vegetative stage of development, when the first and second true leaves were established, seedlings were hand thinned into two per hill to achieve desired the targeted plant densities. In 2008, some missing hills were needed to be replanted about 14 days after planting (DAP).

Weed control was done two times before the 1st and 2nd watering in both years. Thereafter, hand weeding was performed as needed. Plots were surface irrigated four times during both growing seasons. In 2007, no fertilizers were applied to the field experiment because there was a fully absence of it from the markets. In 2008, a 15.5 kg P_2O_5 fad^{-1} was added during seedbed preparation as calcium triple super-phosphate. Nitrogen was applied as ammonium nitrate (NH_4 NO_3) at a rate of 67 kg N fad^{-1} in two equal doses following the first and second watering, respectively. Plants were hand-harvested three times at 150, 157 and 163 DAP. In 2008, Malathion 1% a.i. (2-[(dimethoxy phosphorothioyl) sulfanyl] butanedioate) was sprayed twice at 7-d interval three weeks prior to harvesting to protect against aphids (*Aphis spp.*).

Harvesting (hereafter named Factor C) was done at 150, 157 and 163 DAP. At harvesting, A per-plot five-plant random sample was collected from the central three ridges to measure: plant height, number of primary, secondary and total branches plant^{-1}, pods plant^{-1} and pod weight plant^{-1}, seeds pod^{-1}, weight of seeds plant^{-1}, and 1000-seed weight in three replications. Seed and straw yields per unit area were determination by harvesting the central three ridges of each plot. To estimate seed moisture content, a 25-g seed sample from each plot was dried in the oven at 105°C for 24-48 hours. Seed oil percentage was determined according to A.O.A.C (1984) using Soxhelt apparatus and petroleum ether (60 - 80˚c) as an organic solvent. Seed oil yield was calculated per unit area for each plot.

Confounding design

Twenty seven factorial combinations were tested in a completely confounded 3^3 factorial design with four replicates (Table 1) according to the plan of Cochran and Cox (1957). The effect of the higher order ABC interaction, i.e. plant density x cultivar x harvest time, was totally confounded with incomplete blocks. The ANOVA of this design is shown in Table 2. Data were statistically analyzed according to the procedures outlined by Cochran and Cox (1957) using SAS. Data were analyzed using PROC GLM procedure.

Table 1. The field layout of four replicates in completely confounded design (Cochran and Cox, 1957, p. 238).

Rep. I		
Block1	**Block2**	**Block3**
000	100	200
110	210	010
220	020	120
101	201	001
211	011	111
021	121	221
202	002	102
012	112	212
122	222	022

Rep. II		
Block1	**Block2**	**Block3**
000	100	200
110	210	010
220	020	120
201	001	101
011	111	211
121	221	021
102	202	002
212	012	112
022	122	222

Rep. III		
Block1	**Block2**	**Block3**
000	100	200
210	010	110
120	220	020
101	201	001
011	111	211
221	021	121
202	002	102
112	212	012
022	122	222

Rep. IV		
Block1	**Block2**	**Block3**
000	100	200
210	010	110
120	220	020
201	001	101
111	211	011
021	121	221
102	202	002
012	112	212
222	022	122

Table 2. The ANOVA for a 3^3 completely confounded factorial design in which the ABC effect is completely confounded with the incomplete effect.

SOV	df
Rep	3
B/r	8
Plant density (A)	2
Cultivar (B)	2
A×B	4
Harvest time (C)	2
A×C	4
B×C	4
A×B×C†	8
Error	70
Total	107

† ABC was totally confounded with blocks effect and therefore not possible to separate.

Relative efficiency

Before calculating the relative efficiency of the confounded design to RCBD, it was necessary to estimate the experimental error E_r which would have been present if the experiment had been laid out in randomized complete blocks. This is according to Cochran and Cox (1957). From using the results of the analysis of variance of a confounded experiment, the estimate E_r is:

$$E_r = \frac{n_b E_b + n_e E_e}{n_b + n_e}$$

Where:

Thus in this research with 4 replicates of a 3^3 design in blocks of 9 units, the same interactions being confounded in both replicates, we have:

$n_b = 8,$ $\qquad$ $n_e = 107 - 3 - 8 = 96$.

Hence, values of the relative efficiency were calculated using Microsoft Excel program by the following formula:

RESULTS AND DISCUSSION

1. Relative Efficiency of the Confounded Design

i. Confounding model precision and validity

The confounded design studied here seemed satisfactory to fit the data of most dependent variables in this study. The values of the coefficient of multiple determination, R^2, were fairly high to high among 8 out of the 12 canola characters (Tables 3 and 4). These values ranged from about 75% to 91%. This indicates that the confounded model fitted explained the variation in the dependent variables reasonably well. Values of R^2, on the other hand, for the other four dependent variables, were low since they were in the range of about 59% to as low as 44%.

Regarding the high 8 R^2, three of which were associated with harvest index (HI) (Table 3) and its two related variables – total seed yield (Table 3), and total straw yield (Table 4). These three R^2 values were >85% as the case for straw yield. The three yield components –seed weight plant^{-1}, pod number plant^{-1}, and pod weight plant^{-1}—were best fit by at least 75%. Surprisingly, both percentage seed oil and oil yield were explained by 89% and 86%, respectively (Table 4). On the other hand, the low 4 R^2 values were related to 1000 seed weight, total number of branches plant^{-1} (Table 3), seed number pod^{-1} and plant height (Table 4).

Generally, there was not a general apparent detected trend concerning the resulted R^2 values among the 12 canola characters. There were some variations, for example, in the R^2 values among seed yield-related characters. Measurement scale seemed to partially contribute to these variations. There was a variation between characters that are measured on a ratio scale such as seed weight per plant, 1000-seed weight, and pod weight per plant. Values were in the range of about 35% with a median of about 52%. Likewise, there were variations among characters that were based on enumeration or frequency as the case of number per plant for each of total branch, pods, seeds; values were in the range of 32% with a median of 55%. Despite the closeness in both range and median for the two groups, yet, ratio scaled-based characters had, on the average, higher R^2 values.

Table 3. Analysis of variance, coefficient of multiple determination, R^2, coefficient of variation, CV% for seed yield, seed weight plant^{-1}, harvest index, total branches pl^{-1}, and pod pl^{-1} averaged over 2007 and 2008 seasons.

		SS	**Pr>F**	**SS**	**Pr>F**	**SS**	**Pr>F**	**SS**	**Pr>F**	**SS**	**Pr>F**	**SS**	**Pr>F**
SOV	**df**	**Seed yield**		**Seed wt. Pl^{-1}**		**1000 Sd wt.**		**HI**		**Total B. Pl^{-1}**		**Pod Pl^{-1}**	
Rep	3	80183.0	0.0001	5.8	0.6489	0.8	0.0052	48.0	0.0001	9.9	0.7125	2006.2	0.3784
B/r	8	9493.2	0.7222	51.9	0.0849	0.2	0.8610	22.4	0.2261	35.2	0.7701	4516.8	0.5363
A	2	134698.7	0.0001	142.2	0.0001	0.9	0.0014	464.1	0.0001	5.1	0.7025	25437.6	0.0001
B	2	77014.5	0.0001	128.3	0.0001	0.8	0.0017	94.3	0.0001	60.2	0.0199	3262.6	0.0855
AB	4	244457.0	0.0001	106.1	0.0001	0.1	0.7429	373.3	0.0001	42.5	0.2225	10227.0	0.0056
C	2	7673.0	0.1250	26.7	0.0279	0.3	0.0589	40.7	0.0002	111.4	0.0010	3213.3	0.0886
AC	4	51397.9	0.0001	60.1	0.0039	0.3	0.2478	126.6	0.0001	15.2	0.7191	5965.9	0.0644
BC	4	117379.2	0.0001	85.9	0.0003	0.5	0.0739	31.8	0.0067	23.7	0.5193	20783.1	0.0001
ABC	8	141298.6	0.0001	138.1	0.0001	0.5	0.4552	226.1	0.0001	74.9	0.2635	43441.7	0.0001
Error	70	125327.7		247.9		4.4		143.5		509.0		44821.9	
Total	107	1022158.7		1011.0		9.2		1641.6		912.0		191421.7	
R^2		0.877		0.754		0.518		0.912		0.441		0.765	
CV%		4.08		10.80		6.70		3.10		11.37		6.13	

Characters that were calculated per unit area, e.g. total seed and straw and oil yield yields, all had both high and closeR^2 values. This may indicate that some different lurking variables may have contributed to obtaining such variation among both related and unrelated variables.

Table 4. Analysis of variance, coefficient of multiple determination, R^2, coefficient of variation, CV% for pod weight pl^{-1}, seed pod^{-1}, plant height, straw yield, percentage oil, and oil yield averaged over 2007 and 2008 seasons.

		SS	**Pr>F**	**SS**	**Pr>F**	**SS**	**Pr>F**	**SS**	**Pr>F**	**SS**	**Pr>F**	**SS**	**Pr>F**
SOV	**df**	Pod wt. Pl^{-1}		Seed Pod^{-1}		Plant height		Straw yield		Oil %		Oil yield	
Rep	3	440.6	0.0194	34.2	0.1132	116.2	0.1027	3308.8	0.7957	1.0	0.0083	10574.7	0.0001
B/r	8	306.6	0.5065	15.4	0.9437	47.7	0.9518	22914.8	0.5332	0.6	0.4883	1312.7	0.7801
A	2	413.2	0.0097	30.2	0.0719	423.3	0.0001	433245.1	0.0001	44.9	0.0001	18231.2	0.0001
B	2	1443.6	0.0001	24.4	0.1178	263.7	0.0013	39079.7	0.0038	0.0	0.9041	11048.4	0.0001
AB	4	845.8	0.0012	29.7	0.2621	361.6	0.0013	193120.4	0.0001	0.2	0.4702	33986.7	0.0001
C	2	14643.6	0.0001	55.1	0.0095	361.6	0.0002	57714.7	0.0004	0.2	0.2695	794.4	0.2447
AC	4	357.0	0.0850	47.8	0.0824	128.4	0.1439	216893.7	0.0001	0.2	0.5503	6549.8	0.0004
BC	4	301.2	0.1375	136.1	0.0003	41.8	0.6792	96461.8	0.0001	0.2	0.6184	15948.4	0.0001
ABC	8	868.9	0.0149	86.5	0.0651	108.3	0.6487	149877.0	0.0001	0.6	0.4563	18959.3	0.0001
Error	70	2920.8		387.3		1267.1		226420.3		5.8		19355.3	
Total	107	22917.2		864.4		3146.4		1506445.6		54.5		141336.6	
R^2		0.872		0.551		0.597		0.849		0.893		0.863	
CV%		13.3		9.69		2.87		4.67		0.77		4.30	

The coefficient of multiple determination, R^2, is intended to express how the different model's independent variables have contributed to explain the variation in the dependent variable (Draper and Smith, 1980). This is expressed as the sum of squares related to the fitted model relative to the total sum of squares; this implies that the less the residual error sum of squares, the higher the contribution of the different independent variables to explain the variation in the dependent variable. This is quite reflected in getting a higher R^2 value. Hence, in a way, R^2 is a way of measuring precision, i.e. reliability.

The coefficient of variability, CV%, as a measure of relative variability, gives, in general, and indication of the amount of variation in a population by expressing the standard deviation as a fraction of the mean for a given trait (Bowman and Watson, 1997). The CV% expressed quite reasonable values (Tables 3 and 4). They ranged from as high as 13.30 % for per plant pod number (Table 4) to as extremely low as <0.1 for percentage oil (Table 4). This extremely low value, as well as the like, raises a red flag for the experimenter. It has been known that the CV assumes the variance is proportional to the size of the mean as Bowman and Watson have indicated. In other words, increasing variance is associated with increasing mean. Unusual high CV values among trials within a series of experiments indicate some variables not included in the scope of the experiment might have caused the residual error to inflate. In this case, some experimenters have had so far the tendency to exclude a trial's results based on this 'uncommon' high CV value(s) although Casler and Undersander (2000) warned not to reject trial's data on this basis alone. However, nobody has yet questioned the CV values on the other end of the scale, i.e. when small spread (variance) is associated with large size of mean in a trial.

Across 12 canola traits, the association between both coefficients of multiple determination (R^2) and of variation (CV) was negatively correlated as measured by Pearson's coefficient of correlation (r = - 0.40). In this particular case, the confounded model reliability or precision was negatively related to trial's measure of validity. This implies that the model was successful as far as precision is concerned in detecting differences in treatment effects as indicated by the coefficient of determination (R^2); however, the accuracy as expressed by the coefficient of variability (CV) needs more concern.

ii. Confounding plant density x cultivar x harvest time effect

This confounded model though quite fit the data of all dependent variables (Pr<0.005) except for total branches plant^{-1} (Pr=0.731) (data not shown), the incomplete blocks within replicates failed (Pr>0.05) (Tables 3 and 4) to account for likely sources of variability that may have occurred within the experimental area. This situation most likely may have arisen should the block had not been well oriented and/or heterogeneity between plots within the block been high (Gusmão, 1986; Brownie et al., 1993; and Lin et al, 1993). In addition, also block size and shape contribute to minimizing these sources of variability (Warren and Mendez, 1981). Casler and Undersander (2000) argued against the argument of increasing treatments within block would cause block heterogeneity to sharply rise. This most definitely leads to raising experimental errors. This did not occur when they assessed RCBD since the correlation coefficient between the RE (relative efficiency) and the number of alfalfa (*Medicago sativa* L.) cultivars was r=0.04 (Pr>0.05). They concluded, therefore, that although the RCBD is often inefficient, this was due to reasons other than an excessive number of cultivars in some trials.

In the current study, these incomplete blocks of 9 plots each did not fulfill the objective for its usage. They did not guard against possible variations by grouping as much as possible similar plots according to direction of soil gradient. Or, they did not minimize variations that may have existed between plots within each block. This was based on the little magnitude of the incomplete block/replicate effects for any canola character (Pr>0.05) (Tables 3 and 4). Apart from large block size which Casler and Undersander (2000) denied as a possible explanation for the inefficiency of RCBD, perhaps in the current study improper incomplete block orientation and/or high variation among plots within block were what they referred to by "*other reasons*".

In theory, the pooled error sum of squares in a factorial layout in an RCBD explains each of the main and all interaction effects with replicates. Likewise, as Cochran and Cox (1957, p. 184) have indicated, the pooled error sum of squares in a confounded factorial layout is made up of interactions between treatments and incomplete blocks. Since the three-way interaction, in this study, was the one that was confounded, hence, the way this design was laid out, their effect should be excluded from the pooled experimental error and be part of the incomplete block effect. Cochran and Cox (1957, p. 184) hold that the reduction in effective block size is attained by making the confounded effect (here the three-way interaction) the same as one of the block comparisons.

Although the ANOVA (Tables 3 and 4) shows the three-way interaction, ABC, as a source of variation, this is does not mean that its effect can be tested. This since this ABC effect is partially influenced by differences that may exist among the set of incomplete blocks according to the ABC components, which had been completely confounded within blocks according the design layout (Cochran and Cox, 1957; and Mead, 1984).

A successful confounded design is in fact the one that excludes the interaction that may exist between the assigned confounded effect(s) and incomplete blocks from the pooled error sum of squares and be confounded completely with blocks within replicates. As a matter of fact, the magnitude of the reduction caused by sum of squares of (plant density x cultivar x harvest time) interaction with replicates was not high enough to compensate for the deduction of these 8 degrees of freedom from the pooled error degrees of freedom. This resulted in trivial change in pooled error sum of squares, and therefore it did not add much to the blocks within replicate sum of squares.

iii. Relative efficiency (RE) of the confounded design to the RCBD

Estimation of the gain in precision from confounding, as has been called by Cochran and Cox (1957), is based on how a confounded design relates to the control design, which usually is the RCBD. These authors mentioned that the precision gained by confounding depends on the magnitude of the reduction in the experimental error by decreasing the number of entries within a block. So, the comparison between the two designs is basically a comparison between an incomplete block contains a subset of entries, which had been chosen according to a designed plan, and the complete set of entries had the RCBD been laid out.

Out of 15 dependent canola characters, only three (20%) characters maintained RE values >100% relative to the RCBD (Fig.1). This in addition to the low magnitude of this precision since the gain was as high as only about 7% for only one character. On the other hand, the other 12 showed RE values as low as about 95%. Percentage oil showed about perfect RE (100%), implying that the precision of this chemically-estimated trait was not affected by reducing block size. Casler and Tageldin (1996) found that the precision of neither in vitro dry matter digestibility, IVDMD nor neutral detergent fiber, NDF, concentration, was influenced by variations in plot size, number of strips, and number of plots per strip. They further concluded that experimental design recommendations for forage yield should not affect error variation for IVDMD or NDF concentration.

Hence, in the current study, the precision due to reducing block size from a complete one of 27 entries-blocks, in case of laying out an RCBD, to a 9-entries incomplete blocks by confounding the higher-order interaction did not contribute much to gain in precision. Although larger blocks, in complete or incomplete block designs, tend to contain groups of units that are more heterogeneous than small blocks (Lin and Binns, 1984), this general trend of poor efficiency of the confounded design was not expected. Nevertheless, efficiency is not associated solely with the number of entries within a block as Casler and

Undersander (2000) have indicated. The balanced incomplete block designs may result in a loss of efficiency in the unlikely situation in which complete blocks are as homogeneous as incomplete blocks (Cochran and Cox, 1957).

The latter two authors have reported that balanced incomplete block designs with block sizes of two to five experimental units may have minimum efficiencies as low as 55% relative to a complete block design. Under local soil conditions that are rather more heterogeneous than those reported above, using 9-plot incomplete blocks to get a minimum of about 95% RE, is most encouraging. However, a summary of 685 field crop experiments using balanced or partially balanced lattice designs indicated that only 16 experiments (2.3%) had an effective mean square error greater than that expected for the comparable complete block design.

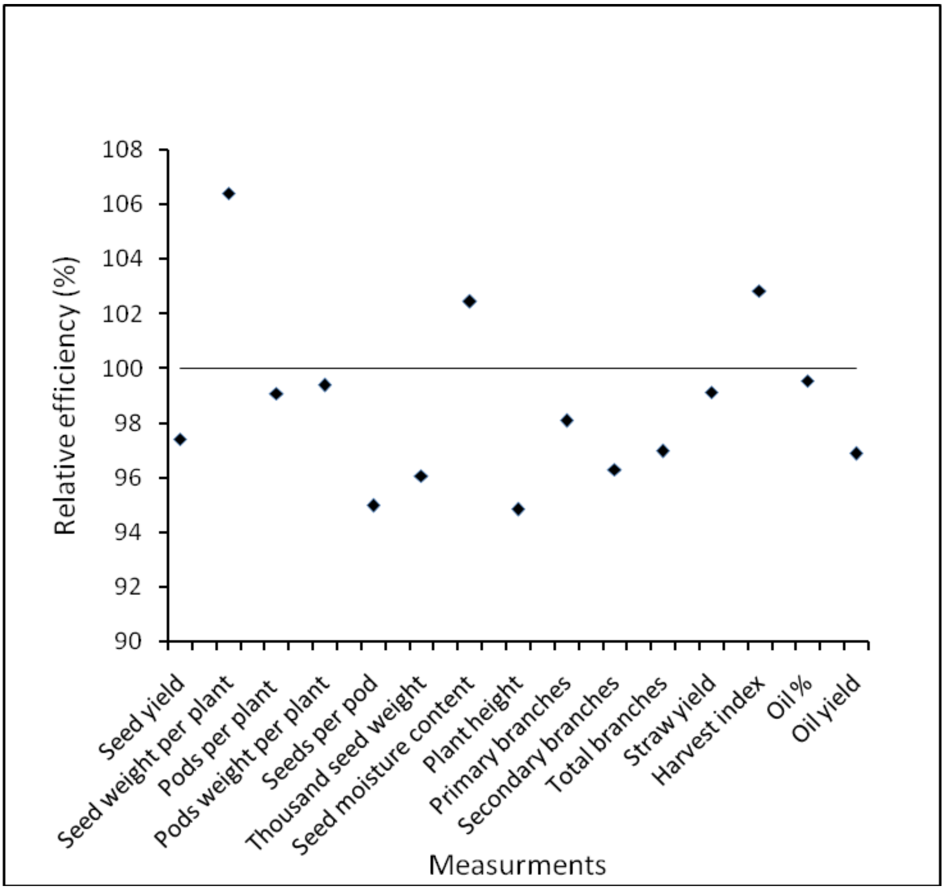
It is important to note that these above-mentioned field experiments were mostly carried out under situations of rainy conditions, implying that no physical barriers of what surface irrigation requirement of pathways nor manual crop management are carried out. Yet, under local soil conditions, this improbable situation as described by Cochran and Cox (1957), in which incomplete blocks are as homogeneous as incomplete ones, is much harder to obtain where soil is subjected, in both the short and the long run, to different inherent soil factors, as well as crop management procedures, that both greatly impact soil fertility gradient within an experimental field.

Whether blocks within replicate sum of squares was effective, this is only an indication of how different blocks were grouped effectively to handle soil variability. This does not necessarily indicate how efficient the confounded layout was relative to the RCBD had it been laid out. Pearson's correlation coefficient between blocks within replicates mean square and RE (confounded design to RCBD) was r = - 0.011 (Pr>0.05). Apparently, both aspects evaluate two different things. Thus, the RE is rather controlled by direct factors that affect the magnitude of the pooled residual error. Yet, significance of blocks within replicates may indirectly influence the magnitude of the reduction in the error sum of squares, and the former may, in turn, determines how relative this reduction in magnitude to the improvement in the RE of the tested confounded design.

Factors related to experimental design such as plot size, block size, and block shape affect error variation (Casler and Tageldin, 1996). They aggregated 288 individual plot data into incomplete blocks of varying sizes and shapes in one, vs. three strips of 12 plots each of four different plot sizes, 1.4, 2.8, 4.2, and 5.6 m^2. A 0.92-m alley was between strips of plots. This was for orchard grass (*Dactylis glomerata* L.) forage yield, IVDMD), and NDF concentration. Mean values of log pooled variance (V_w) of forage yield were 71% higher for three-strip blocks than for one-strip blocks.

Crop management practices most likely contribute to variations in precision of field experiments. Of these practices is how harvesting is actually practiced in the field, depending of course on the growth nature of any specific crop. In case of forage crop field trials, e.g. orchard grass trials, a standard practice is to cut first the inter-alley forage plants by a 0.92-m wide flail-type harvester prior to each harvest. Accordingly, Casler and Tageldin (1996) argued that the three-strip incomplete blocks were probably more sensitive to variations in plot length caused by inconsistency in removal of the inter-strip alleys, with four alleys for three-strip blocks, compared with two alleys for each one-strip blocks.

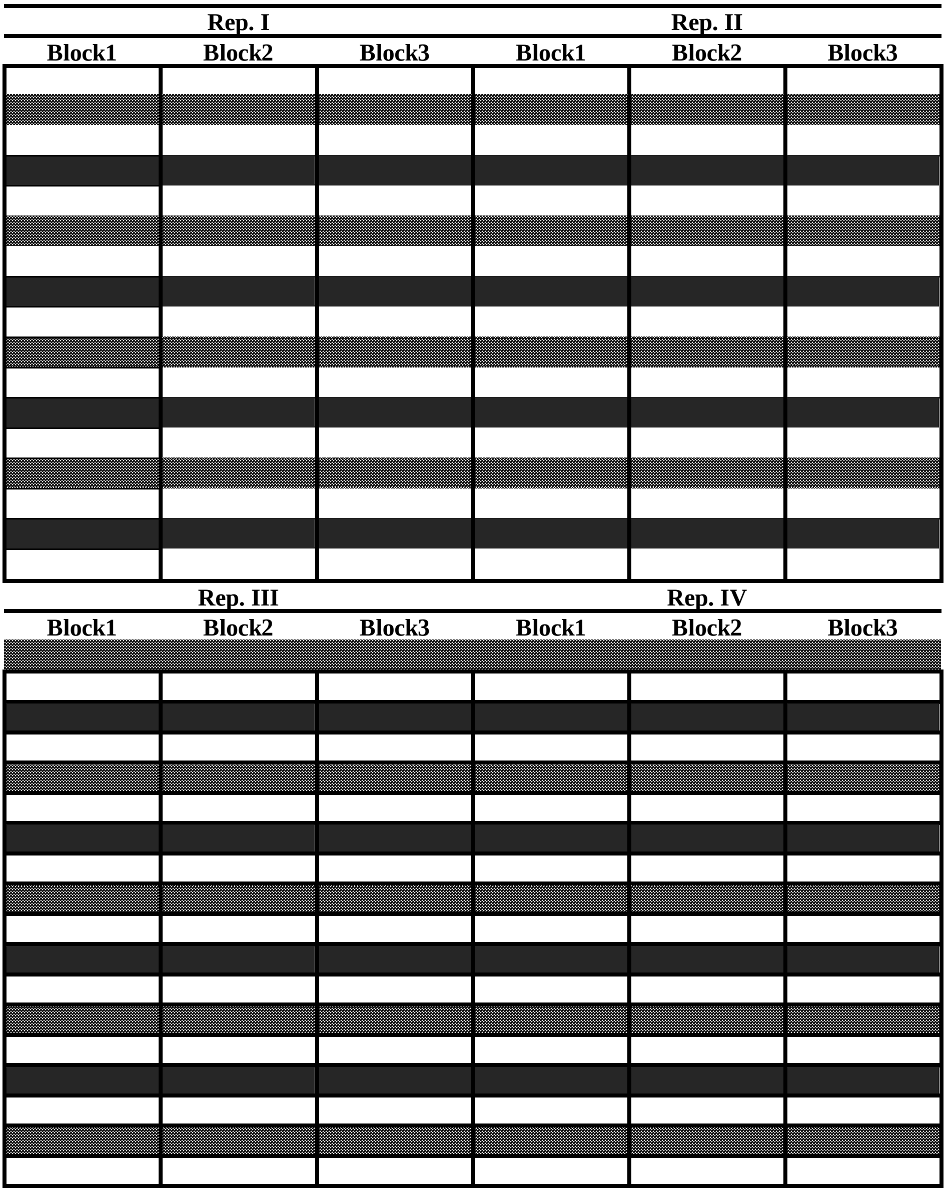
Figure 1. Relative efficiency (RE) of the confounded design relative to the RCBD for all measurements averaged over 2007 and 2008 seasons.



Moreover, the authors also found that increasing the number of plots per strip increased log (V_w) for forage yield to a greater extent for three-strip blocks than one-strip blocks. For a constant number of plots per incomplete block, the three-strip and one-strip incomplete blocks were equal in precision: log (V_w) = 0.06 vs. 0.07 for 3 x 2 and 1 x 6 incomplete blocks, and 0.11 vs. 0.10 for 3 x 4 and 1 x 12 incomplete blocks. They, therefore, infered that the effect of three-strip vs. one-strip incomplete blocks appeared to be due to multiple strips per se, rather than the shape of the incomplete block, i.e. length:width ratio or the number of plots within an incomplete block. Increasing number of plots within block was not the only reason for the reduction in the efficiency as indicated by Casler and Undersander (2000).

As far as the relationship between the effect of the incomplete block on precision, the nature of the trials needs elaboration regarding the current trial and Casler and Tageldin's (1996) field trial. First, according to Fig. 2, both the 1-m width watering pathways and the 0.70-m inter-plot borders represent, to a great extent, the field layout of the other study. This, of course in the sense of laying out the incomplete blocks in strips, however, these physical barriers outnumbered and were wider than those existed in the other trial. These barriers exhibit some features of high soil heterogeneity within incomplete or complete blocks such as higher inter-plot border effects, in additiont to those resulted from water pathways

Figure 2.Field diagram of three 9-plot incomplete blocks in each of four replicates. Cross-hatched horizontal bars represent 1m-wide water pathways. Dark horizontal bars and dark vertical lines represent 0.70-m borders between plots. Plain rectangular areas represent 3.5-m wide x 3.0-m long plots.



to contiguous plots due to both surface and subsurface water leakage to these plots.

Second, the growth nature of the growth of each crop, canola vs. orchardgrass, exhibited also a great influence on plot to plot homogeneity within the incomplete block. Canola produces both primary and secondary tillers on which seed pods are produced. This nature of growth necessitate that seeds planted in distant hills. It is very likely that experimenters experience missing hill problems, which therefore aids in increasing within-plot variation as do plant-to-plant variations in branching habit. On the other hand, orchardgrass is a bunch-type forage crop in which plants tiller sufficiently to create satisfactory and uniform cover.

Other plot-to-plot variations also exert some negative effects on error variance. During the course of the field trials over 2 years, some plots had some missing hills all over the trial regardless of the different plant densities which was a one main factor being studied. If this had occurred within low plant density level such as the 7.1 plant m^{-2} density, this would have increased the probabilty of much more plot heterogeneity compared with those plots that had higher plant densities, the 10 and the 11.9 plant m^{-2} plant density. Usually variations associated with smaller harvested area within a plot adversely affect precision relative to larger harvested areas. Other source of variation is related to the likelihood of pod shattering which is a common growth phenomenon associated with some canola cultivars especially if harvesting is delayed as was really happened in this study.

The sensitivity of a field experiment to changes in block size is extremely variable (Warren and Mendez, 1981), indicating that conclusions from a uniformity experiment may apply strictly to the particular crop-site combination on which the experiment was based as reported by Casler and Tageldin (1996). Warren and Mendez (1981) classified uniformity experiments based on very much different crop species, and grown in very different climates and with very different plot sizes as sensitive or relatively insensitive to blocking. Generally, this therefore implies that both field crop and site specifications are both limiting factors regarding blocking effect, warranting careful discretion of generalization from site to site or crop to another disregarding this sensitivity to block size.

Physical field barriers represent, therefore, one considerable soil fertility gradient that probably affect block orientation. In this canola field trial, incomplete block orientation that occurred perpendicular to these necessary physical barriers apparently may seem one gradient that was responsible to the nearly equal RE of the confounded design. Other unknown complex soil fertility gradients may also exist so that the reduction in the size of the incomplete block did not significantly account for. In trying to account for soil spatial variations at the same location, Tageldin (2004) evaluated spatial analyses methods using 16 barley (*Hordeum vulgare* L.) genotypes. Relative to RCBD, the RE of 4 x 4 lattice design ranged from 69-120%, for correlated error (CE) model, from 86-106%, and for nearest neighbor analysis (NNA) from 112-171%. This indicates that soil fertility gradient is more complex so that spatial analyses seemed useful to account for intra block soil spatial variation since most often it is hard for experimenters to have a priori knowledge about the proper way to lay out blocks in the field.

Casler and Tageldin (1996) reported that increasing the size of the harvested unit parallel to the direction of a gradient, if known, is generally more efficient than increasing harvested unit size in the perpendicular direction. Based on this argument, in this specific site, future field trials concerning confounding, laying out incomplete blocks parallel to these water pathways is recommended. The location inherent complex nature of soil fertility gradient necessitates taking more careful measures regarding both experimental design factors and the field crop growth nature. This is of course does not imply that these measures would guarantee to a great extent higher precision.

2. Plant Density, Cultivar and Harvesting Time

Plant height, primary, secondary and total branches per plant

Table 5 showed that each of plant height, secondary and total branches were affected significantly by plant density and harvest time. The effect of cultivar was significant for plant height and was not for the branches. Primary branches per plant were significantly affected by harvest time only. Cultivar × plant density interactions were significant for plant height and secondary branches while they were not for primary and total branches. Neither cultivar × harvest time nor plant density × harvest time interactions exhibited any significance effect on each of plant height, primary, secondary, and total branches per plant (P-value, Table 5).

Plant height was significantly affected by cultivar, plant density, their interaction and harvest date (Table 5). Within each main effect, the differences in plant height were not exceeding five centimeters (Table 6). Johnson and Hanson, (2003) considered three centimeters differences in plant height, is not a significant concern for either research or commercial production. Varietal differences in plant height were observed also in studies by (Harker et al., 2003; Johnson and Hanson, 2003; Ozer, 2003; and Lamb and Johnson 2004). The argument of Johnson and Hanson (2003) may further be explained on the basis that a little increase in plant height as far as 3-cm difference is not enough to allow for more branches to develop on the plant to carry more pods which is turn contribute to seed yield per plant. This is supported by the data (Table 6) since the varietal marginal differences in plant height were quite parallel to differences in primary, secondary and total branch number per plant. Moreover, a quite similar trend on plant height and branching was exhibited by changing plant density (Table 6). The cultivar × plant density interaction for plant height though significant (P= 0.0013, Table 5), all means fall within only a 10-cm range (144.7 cm for Pactol × 9.5 plants m^{-2}vs 155.3 cm for AD201 × 11.9 plants m^{-2}). This 10-cm differential yielded a primary branch margin of only less than 1 (8.10 vs 7.73) for primary and (22.90 vs 23.67) for total branches. Despite the significant cultivar × plant density interaction for secondary branching, the differential was not quite different either.

There was no significant main effect of cultivars on either number of primary, or secondary, or total branches per plant (Tables 5 and 6.). These characters averaged 8; 15.7; 23.7 branches per plant, respectively. Ozer (2003) reported similar results, as number of total branches per plant was similar for two *Brassica napus* L cultivars Tower and Lirawell.

The only interaction of cultivar × plant density was observed only for the number of secondary branches per plant. The highest number of secondary branches for AD201 (16.68 branch) was achieved at densities of 7.1 plants m^{-2} and more than other densities by an average of 9.3 %, while the highest number for Serw4 (averaged 16.53 branch) was achieved at densities of 7.1 and/or 9.5 plants m^{-2} and more than other density by 16.5 %, whereas Pactol variety achieved the highest number (averaged 16.14 branch) at densities of 9.5 and/or 11.9 plants m^{-2} and more than other density by 3.1 % (Table 5).

As an absence of the significant effect of plant density on primary branches (Table 5), therefore the significant differences in number of total branches per plant was due to the significant differences in numbers of secondary branches only as affected by whether plant densities and cultivar × plant density interactions.

Table 5. Analysis of variance (P values) and effect of the possible two-way interactions between cultivars, plant densities and harvest time on plant height, number of primary, secondary and total branches, adjusted means were averaged over 2007 and 2008 seasons

Cultivar	**Actual plant density**	**Harvest time†**	**Plant height**	**Branch plant^{-1}**		
				Primary	**Secondary**	**Total**
	no. m^{-2}	— d —	— cm —			
				Tow-way interactions		
	7.1	-	148.58	7.78	16.68	24.47
AD201	9.5	-	146.77	7.71	15.44	23.15
	11.9	-	155.32	8.10	14.80	22.90
	7.1	-	145.84	8.85	15.64	24.50
Pactol	9.5	-	144.72	7.73	15.94	23.67
	11.9	-	145.95	7.52	16.35	23.87
	7.1	-	151.35	8.15	16.61	24.77
Serw4	9.5	-	146.82	8.11	16.45	24.57
	11.9	-	148.34	7.68	13.80	21.48
				NS		NS
	-	150	148.23	7.64	15.22	22.87
AD201	-	157	148.59	7.64	15.30	22.94
	-	163	153.85	8.32	16.39	24.71
	-	150	147.06	8.34	16.11	24.45
Pactol	-	157	143.08	7.35	15.05	22.40
	-	163	146.37	8.42	16.77	25.19
	-	150	149.00	7.85	15.75	23.61
Serw4	-	157	146.31	7.53	14.62	22.16
	-	163	151.20	8.56	16.49	25.06
			NS	NS	NS	NS
		150	149.05	8.36	16.71	25.08
-	7.1	157	146.90	7.47	15.41	22.89
		163	149.83	8.95	16.82	25.77
		150	145.25	7.93	16.01	23.95
-	9.5	157	144.18	7.57	15.32	22.90
		163	148.89	8.05	16.50	24.55
		150	149.99	7.54	14.36	21.91
-	11.9	157	146.91	7.47	14.24	21.72
		163	152.70	8.30	16.34	24.64
			NS	NS	NS	NS
SE			1.228	0.323	0.548	0.778
				ANOVA		
Source of variation			P values			
Replication			0.1027	0.7989	0.5126	0.7125
Blocks/ rep			0.9518	0.6470	0.8390	0.7701
Cultivar (C)			0.0001	0.8066	0.6751	0.7025
Plant density (P)			0.0013	0.1444	0.0120	0.0199
Harvesting date (H)			0.0002	0.0034	0.0037	0.0010
C × P			0.0013	0.1073	0.0111	0.2225
C × H			0.1439	0.6033	0.8154	0.7191
P × H			0.6792	0.5029	0.4907	0.5193
C × P × H			0.6487	0.9067	0.0607	0.2635

† Harvest at 150, 157 and 163 DAP.

Table 6. The main effects of the cultivars, plant densities and harvest time for plant height, number of primary, secondary and total branches, adjusted means were averaged over 2007 and 2008 seasons.

Main effect	Plant height	Branch plant^{-1}		
		Primary	Secondary	Total
	— cm —			
Cultivar				
AD201	150.22	7.86	15.64	23.51
Pactol	145.50	8.03	15.97	24.01
Serw4	148.84	7.98 NS	15.62 NS	23.61 NS
Plant density / m^{-2}				
7.1	148.59	8.26	16.31	24.58
9.5	146.10	7.85	15.94	23.80
11.9	149.87	7.77 NS	14.98	22.75
Harvest date†				
150	148.10	7.94	15.70	23.64
157	146.00	7.50	14.99	22.50
163	150.47	8.43	16.55	24.99
SE	0.709	0.186	0.316	0.449

† Harvest at 150, 157 and 163 DAP.

Number of both the primary, secondary and total branches per plant was inversely proportional to plant densities ranging from 7.1 to 11.9 plant m^{-2} (Table 6); it linearly decreased from 8.26 to reach 7.77; 16.31 to 14.98; and 24.58 to 22.75 for primary, secondary and total branches, respectively. The previous inverse relationship for previous states has been also observed whether under higher plant densities ranging from 76 to 229 plant m^{-2}for (Serw4) cultivar in research by Taha (2007), or under lower plant densities ranged from 21.7 to 3.6 plant m^{-2} in research by McGregor (1987). In my research at 7.1 plants m^{-2}, the individual plant produced 24.5 branch compared to 15 branch per plant at the same density in research by McGregor (1987). This may refer to the genotypes differences.

Number of primary, secondary and total branches per plant was significantly affected by harvesting date (Table 5). There was a trend (Table 6) showing a linear increase in these characters by approximately 1; 1.5; 2.5 branches per plant, respectively at the latest harvesting date. This tight effect of harvesting date may have occurred due to that these characters were already developed before the first harvesting date treatments. Moreover, neither cultivar × harvest time nor plant density × harvest time interactions exhibited any significance effect on each of primary, secondary, and total branches per plant (P-value, Table 5). Therefore under the conditions of this trial, I may infer that extending harvest time solely positively affected branching.

Based upon the above results, the cultivar effect had no influence on primary, secondary and total branch per plant, while these characters, except primary branches, were significantly affected by plant density. The cultivar × plant density interactions were only significant for the secondary branches. These results suggest that varied plant density lead to variation of total branches and this variation was accompanied with the variability in number of secondary branches, which was strongly affected by plant density. Furthermore, number of primary, secondary and total branch per plant and plant height were affected by the harvesting date. Therefore, producing new primary branches was coincided with the variability in plant height due to harvesting date treatments. These new primary branches also produced secondary branches; consequently the variability in the total number of branches due to harvesting date treatments was observed.

Pods per plant

Accordingly, the varied effects of the interaction(s) among the studied factors on branching seemed to extend to pod traits. Pod traits are shown in Tables 7 and 8. The three cultivars showed differences ($P<0.01$) for each of pod plant^{-1}, pod weight plant^{-1}, and 1000-seed weight (Table 7). Moreover, plant density exhibited differences for the last two traits - pod weight plant^{-1}, and 1000-seed weight. Varying harvest date significantly affected seed pod^{-1} and pod weight plant^{-1}.The interaction cultivar × plant density was different ($P<0.01$) for both pod plant^{-1} and pod weight plant^{-1}. The plant density × harvest time interaction shared significance for pod plant^{-1} and seed pod^{-1}. Taha, (2001) found also differences in pods number plant^{-1} for 15 genotypes and the AD201 produced 110 compared to 89.5 pods plant^{-1} in Pactol. This great difference between results as AD201 and Pactol produced pods as fourfold as those in Taha, (2001) could be related directly to the plant density which is inverse proportional to number of pods per plant. Taha, (2001) used seeding rates of 3 kg per faddan which is theoretically equivalent to more than 200 plants m^{-2} which is mean greater than our densities by approximately 20 folds.

However, in this trial plant density had no effect on number of pods per plant (Table 7). Similar to results of Angadi et al. (2003) he found similar number of pods per plant at density of 5 and 10 plants m^{-2} either under bad or favorable environments. Nevertheless, in many studies (McGregor 1987; Morrison et al. 1990; Angadi et al. 2003; Taha 2007) with varying plant densities ranged from 3.6 to 229 plants m^{-2}, there were an inverse linearly relationship between number of pods per plant and plant density.

The plant density × harvest date interaction effects were significant for the number of pods per plant. At 7.1 plants m^{-2}, more pods per plant were observed at the first harvest date than the others by 8%, while at densities of 9.5 and 11.9plants m^{-2}more pods per plant were observed at the last two harvesting dates than the first one by 5% for both previous densities (Table 7). Overall cultivar and planting density, the number of pods per plant did not differ at different harvesting dates (Table 8).

Seeds per pod

Neither cultivar nor plant density nor their interactions affected the number of seeds per pod (Table 7). These results were similar to findings reported by Angadi et al., 2003 and Ozer, 2003 and in contrast with those obtained by McGregor, 1987 as he reported that number of seeds per pod was increased in some instances with reduced plant density. Taha, (2001) found that Pactol variety recorded 24.8 seeds per pod and 19.2 seed of AD201. Plant density was found to inversely impact the number of seeds per pod on (Serw 4) cultivar (Taha, 2007).

Table 7. Analysis of variance (P values) and effect of the possible two-way interactions between cultivars, plant densities and harvest time on pods per plant, number of seeds per pod, pod weight per plant and thousand seed weight, adjusted means were averaged over 2007 and 2008 seasons.

Cultivar	**Actual plant density**	**Harvest time†**	**Pods plant^{-1}**	**Seeds pod^{-1}**	**Pods wt plant^{-1}**	**1000 seed wt**
	— no. m^{-2} —	— d —			—— g ——	
				Tow-way interactions		
	7.1	-	414.89	26.17	57.40	3.58
AD201	9.5	-	425.32	23.75	44.30	3.70
	11.9	-	440.71	24.71	43.97	3.59
	7.1	-	438.98	24.19	55.07	3.76
Pactol	9.5	-	408.49	24.52	50.75	4.00
	11.9	-	409.33	24.23	46.89	3.71
	7.1	-	399.23	23.95	46.65	3.80
Serw4	9.5	-	380.56	22.60	50.28	3.94
	11.9	-	393.65	24.21	41.41	3.70
				NS		NS
	-	150	424.03	25.20	59.28	3.71
AD201	-	157	426.65	25.00	54.59	3.66
	-	163	430.24	24.43	31.81	3.50
	-	150	411.31	25.54	65.30	3.81
Pactol	-	157	405.10	23.62	54.10	3.90
	-	163	440.38	23.78	33.31	3.77
	-	150	396.07	24.17	57.11	3.70
Serw4	-	157	388.68	24.94	48.02	3.94
	-	163	388.70	21.63	33.20	3.80
			NS	NS	NS	NS
		150	440.26	24.94	64.72	3.58
-	7.1	157	388.83	23.46	59.17	3.90
		163	424.01	25.90	35.24	3.66
		150	390.29	24.84	61.38	3.97
-	9.5	157	413.17	24.24	49.15	3.87
		163	410.91	21.80	34.81	3.80
		150	400.86	25.14	55.60	3.67
-	11.9	157	418.44	25.86	48.39	3.72
		163	424.39	22.15	28.28	3.61
					NS	NS
SE			7.304	0.679	1.864	0.072
				ANOVA		
Source of variation				P values		
Replication			0.3784	0.1132	0.0194	0.0052
Blocks/ rep			0.5363	0.9437	0.5065	0.8610
Cultivar (C)			0.0001	0.0719	0.0097	0.0014
Plant density (P)			0.0855	0.1178	0.0001	0.0017
Harvesting date (H)			0.0886	0.0095	0.0001	0.0589
C × P			0.0056	0.2621	0.0012	0.7429
C × H			0.0644	0.0824	0.0850	0.2478
P × H			0.0001	0.0003	0.1375	0.0739
C × P × H			0.0001	0.0651	0.0149	0.4552

† Harvest at 150, 157 and 163 DAP.

Harvest date effect and its interaction with plant density were only significant for number of seeds per pod (Table 7). The differences in number of seeds per pod at the three harvest dates were less than two seeds per pod (Table 8). Different result was reported by Taha, 2007 as the number of seeds per pod was not affected by three harvesting dates began from 146 days after planting with weekly intervals. At plant density of 7.1 plants m^{-2} (Table 7), more seeds per pod were observed when the harvest date was the latest one, while plant densities of 9.5 and 11.9 plants m^{-2} recorded the highest number of seeds per pod at the first two harvest dates.

Table 8. The main effects of the cultivars, plant densities and harvest time for pods per plant, number of seeds per pod, pod weight per plant and thousand seed weight, adjusted means were averaged over 2007 and 2008 seasons.

Main effect	**Pods plant^{-1}**	**Seeds pod^{-1}**	**Pod wt plant^{-1}**	**1000 seed wt**
			——— g ———	
Cultivar				
AD201	426.97	24.88	48.56	3.62
Pactol	418.93	24.31	50.90	3.82
Serw4	391.15	23.58	46.11	3.81
		NS		
Plant density / m^{-2}				

7.1	417.70	24.77	53.04	3.71
9.5	404.79	23.62	48.44	3.88
11.9	414.56	24.38	44.09	3.67
	NS	NS		
Harvest date†				
150	410.47	24.97	60.57	3.74
157	406.81	24.52	52.23	3.83
163	419.77	23.28	32.78	3.69
	NS			
SE	4.217	0.392	1.076	0.042

† Harvest at 150, 157 and 163 DAP.

Pod weight per plant

Pod weight per plant wassignificantly affected by both cultivar, plant density, their interaction and harvest date (Table 7). Results in table 3 showed thatheaviest pods weight per plant within cultivars was observedat lower densities of 7.1 plants m^{-2}; all means fall within a 16 g range (41.4 g for Serw4 × 11.9 plants m^{-2}vs 57.4 g for AD201 × 7.1 plants m^{-2}).Pods weight per plant was inversely proportional to plant density; it linearly increased significantly from 44 to reach 53 g (Table 8). With delaying the harvest date, pods weight per plant decreased linearly by 14 to 46 % 157 and 163 DAP respectively, compared to the first harvest date 150 DAP (Table 8).

1000 seed weight

Thousand seed weight was affected by cultivar, plant density and harvest time while no any interaction had a significance effect on this character (Table 7). The variability in thousand seed weight within cultivar or plant density was 0.20 g and 0.14 g within harvest time traits (Table 8).Based on data of Taha (2001), thousand seed weight of AD201 was heavier than Pactol by 16.6 % while in this trial Pactol was heavier than AD201 by 5%. Differences in thousand seed weight among cultivars were observed by (Shrief, 1989) and were not by (Ozer, 2003). No differences in thousand seed weight between plant densities of 5 and 10 plants m^{-2} were observed by (Angadi et al., 2003) while McGregor (1987) and Taha (2007) found that thousand seed weight was increased with reduced plant density. In addition,Taha (2007) found that thousand seed weight was not significantly affected by harvesting date treatments.

Seed moisture content

At the latest harvest date the thousand seed weight was not only at the lowest level but also the seed moisture content.Only harvesting date was significant for the seed moisture content (Table 9) while other main effects and interactions were not.With delaying harvest date at 157 and 163, seed moisture content was reduced linearly by 4and 17 %, respectively compared to harvest date at 150 DAP, respectively (Table 10).These results were similar to those observed by (Elias and Copeland, 2001) as seed moisture content (SMC) of all cultivars decreased gradually from initial seed formation to the harvest maturity. Elias and Copeland (2001)found alsonon significance differences in seed moisture content within either two spring or four winter cultivars.

Based on these results, both pod number per plant and plant height wassignificantly affected by cultivar and cultivar × plant density interaction. At the same time, number of branches per plant was not affected by cultivar. Consequently, the variation between these cultivars in pod number per plant may be greatly dependent on plant height as producing new pods on the main shoot or may be related to the differences between these cultivars in the ability of producing more pods on primary and/or secondary branches.

Plant density and harvesting date had no influence on pod number per plant, yet theyaffected number of total branches and thousand seed weight, whereas number of seeds per pod was affected by harvesting date and did not differ by plant density. These results may suggest that plants tended to produce new branches, new seeds per pod and encourage seeds filling as affected by plant density and/or harvesting date, but this may a negative impact on producing new pods.

The variation in per plant pod weight was dependent on those changes in both pod number per plant and 1000 seed weight. These three traits were affected by either cultivar, plant density, cultivar × plant density or by at least two. On the other hand, per pod seed number and seed moisture content were affected by neither of the above factors nor their interaction. Thus, varying the number of plants per unit area within any given cultivar and/or between different cultivars seem to be a limiting factor for all these yield components – pod weight, pod number, and 1000-seed weight.

As a result of a significance impact of harvesting date on pod weight per plant, number of seeds per pod, seed moisture content and thousand seed weight, therefore the variability in pod weight per plant was due to the variability in both number of seeds per pod occurred during the period of pod extension and seed moisture content as reduced linearly by delaying harvesting and thousand seed weight as varied by seed filling period and/or by variation in seed moisture content.In addition pod moisture content may also affect pods weight per plant.

Seed weight per plant

Seed weight per plant was affected significantly by cultivar, plant density (Table 9). Similar results were obtained by (Shrief, 1989). The cultivar × plant density interaction for seed weight per plant though significant (P= 0.0001, Table 9), all differences between means fall within only a 6 g range (14 g for Serw4 × 7.1 plants m^{-2}vs 20 g for Pactol × 9.5 plants m^{-2}).

There was a significant effect of harvesting date and its individual interactions with cultivar and plant density on the seed weight per plant (Table 9). Taha, (2007) found no differences in seed weight per plant among harvesting date treatments. With delaying the harvesting date from 150 to 163 DAP, seed weight per plant was linearly decreased from 18 to 17 g plant^{-1} (Table 10). With delaying the harvest date from 150 to 163 DAP; seed weight per plant was linearly decreased by 11 and 8 % for

AD201 and Pactol, respectively, whereas it linearly increased by 7 % for Serw4 (Table 9).

At 7.1 plants m^{-2}, with delaying the harvesting at 157, 163 DAP, the seed weight per plant increased by 5 %, while it decreased by 15 % for plant density of 9.5 plants m^{-2} compared to 150 DAP, whereas harvesting at whether 150

Table 9. Analysis of variance (P values) and effect of the possible two-way interactions between cultivars, plant densities and harvest time on seed moisture content, seed weight per plant and seed yield, adjusted means were averaged over 2007 and 2008 seasons.

Cultivar	**Actual plant density**	**Harvest time†**	**SMC‡**	**Seed wt plant^{-1}**	**Seed yield**
	— no. m^{-2} —	— d —	— % —	— g —	— Kg fad^{-1} —
			Tow-way interactions		
	7.1	-	12.25	20.00	1036.59
AD201	9.5	-	12.08	18.20	1159.87
	11.9	-	12.27	16.49	1035.01
	7.1	-	12.20	18.00	1033.35
Pactol	9.5	-	12.21	20.29	1119.37
	11.9	-	12.27	16.41	975.12
	7.1	-	12.16	14.42	1038.35
Serw4	9.5	-	12.15	17.70	931.16
	11.9	-	12.27	15.28	1004.09
			NS		
	-	150	13.05	19.66	1101.67
AD201	-	157	12.60	18.28	1084.75
	-	163	10.95	16.75	1045.05
	-	150	13.14	19.23	1018.58

Pactol	-	157	12.70	18.27	1056.39
	-	163	10.85	17.20	1052.87
	-	150	13.22	15.25	1025.99
Serw4	-	157	12.60	15.59	957.30
	-	163	10.76	16.55	990.31
			NS		
		150	13.14	16.87	1037.96
-	7.1	157	12.58	17.91	1045.15
		163	10.89	17.63	1025.19
		150	13.16	20.74	1115.16
-	9.5	157	12.56	18.75	1086.86
		163	10.72	16.69	1008.37
		150	13.10	16.53	993.12
-	11.9	157	12.76	15.47	966.44
		163	10.94	16.18	1054.67
			NS		
SE			0.150	0.543	12.214
				ANOVA	
Source of variation				P values	
Replication			0.0424	0.6489	0.0001
Blocks/ rep			0.2489	0.0849	0.7222
Cultivar (C)			0.9560	0.0001	0.0001
Plant density (P)			0.6095	0.0001	0.0001
Harvesting date (H)			0.0001	0.0279	0.1250
C × P			0.9759	0.0001	0.0001
C × H			0.8112	0.0039	0.0001
P × H			0.8443	0.0003	0.0001
C × P × H			0.4562	0.0001	0.0001

† Harvest at 150, 157 and 163 DAP.

‡ Seed moisture content.

Table 10. The main effects of the cultivars, plant densities and harvest time for seed moisture content, seed weight per plant and seed yield, adjusted means were averaged over 2007 and 2008 seasons.

Main effect	**SMC†**	**Seed wt plant^{-1}**	**Seed yield**
	—— % ——	—— g ——	—— kg fad^{-1}——
Cultivar			
AD201	12.20	18.23	1077.16
Pactol	12.23	18.23	1042.61
Serw4	12.19 NS	15.80	991.20
Plant density / m^{-2}			
7.1	12.20	17.47	1036.10
9.5	12.15	18.73	1070.13
11.9	12.27 NS	16.06	1004.74
Harvest date‡			
150	13.13	18.05	1048.75
157	12.64	17.38	1032.82
163	10.85	16.83	1029.41 NS

SE	0.086	0.313	7.052

† Seed moisture content.

‡ Harvest at 150, 157 and 163 DAP.

and/or 163 DAP for density of 11.9 plants m^{-2}, increased seed weight per plant by 5 % compared to harvesting at 157 DAP (Table 9).

The variation in per plant seed weight was dependent on those changes in both pod number per plant and 1000 seed weight. These three traits were affected by either cultivar, plant density, cultivar × plant density or by at least two. On the other hand, per pod seed number and seed moisture content were affected by neither of the above factors nor their interaction. However, at harvest, the observed variation in per plant seed weight was dependent on those changes in both number of seeds per pod during the period of pods extension, 1000 seed weight which caused by either during the period of seeds filling and/or the variation in seed moisture content. All these four traits were affected significantly by harvest time.

Seed yieldper faddan

Seed yieldwas affected significantly by cultivar (similar to findings of Taha, 2001; Harker et al., 2003; Johnson and Hanson, 2003; Lamb and Johnson, 2004 and contrast with Ozer, 2003), plant density (similar to findings of McGregor, 1987; Morrison et al., 1990; Angadi et al., 2003; Harker et al., 2003; Chen et al., 2005 and in contrast with Dosdall et al., 1996;

Dosdall et al., 1998; Taha 2007) and their interactions (contrast with findings of Harker et al., 2003) (Table 5).

Variation in the seed yield as affected by cultivar mainly occurred due to variation in whether pods number per and thousand seed weight which they were affected by cultivar, while seeds per pod and seed moisture content were not.Highest seed yield was recorded for AD201 as 1077 kg fad^{-1} and higher than Pactol and Serw4 by 3 and 8 %, respectively (Table 10).Based on data of Taha, (2001) the seed yield of AD201 was more by 10% than Pactol variety overall four nitrogen levels, furthermore, in research by Taha, (2007) the seed yield of Serw4 averaged 1044 kg Fad^{-1} overall three seeding rates.

The variation in the seed yield per faddan as affected by plant density mainly occurred due to the variation in the thousand seed weight which was affected by plant density, while either number of pods per plant or seeds per pod or seed moisture content were not. Highest seed yield was achieved by 9.5 plants m^{-2} as 1070 kg fad^{-1} and higher than 7.1, 11.9 plants m^{-2} by 3 and 6 %, respectively (Table10).Angadi (2003) found similar seed yield at plant density of 5 and 10 plants m^{-2} under both bad and favorable environment with little exception.

Variation in seed yield as affected by cultivar × plant density interactions mainly occurred due to the variation in pods number per plant which was affected by cultivar and cultivar × plant density interactions, while number of seeds per pod, thousand seed weight and seed moisture content were not.Highest seed yield for AD201and Pactol were observed at 9.5 plants m^{-2} and more than other densities by 11 and 10 %, respectively for these cultivars, whereas highest seed yield for Serw4 was observed at 7.1 plants m^{-2} and more than other densities by 7 % (Table 9).

In this research achieving high seed yield was obtained by 9.5 plants m^{-2}. McGregor, (1987) was mentioned that the seed yield was dropped off rapidly below approximately 8 plants m^{-2}. Further, based on data of Angadi, (2003), the seed yield which obtained by density of 10 plants was less by 20 to 80 % than those obtained by 80 plants m^{-2} overall four trials, in addition, the maximum seed yield obtained in his research at 80 plants m^{-2} was less by 7.5% than ours maximum seed yield which obtained at density of 9.5 plants m^{-2}. These results may be related to whether yield components and also environmental conditions. For instance, in our research the number of pods per plant, thousand seed weight and number of seeds per pod at density of 9.5 plants m^{-2} were higher by 18, 22 and 4%, respectively, than those in research of Angadi, (2003) which obtained by 80 plants m^{-2} overall four trials.

The harvesting date (Table 9) had no significance impact on the seed yield (similar findings of Taha, 2007) and this impact was consistent with pods number per plant while it was inconsistent with the seed weight per plant as it was affected by harvesting date. However, data in table 10 showed that both of seed yield and seed weight per plant were reduced linearly with delaying the harvesting date. This reduction was mainly coincided with linearly decreases in seed moisture content with delaying the harvesting date andmay be related also tosome changes in either number of seeds per pod and/or thousand seed weight.

There was a significant effect of cultivar × harvesting date interactions on seed yield.Although, seed yield was decreased with delaying the harvest at 157, 163 DAP by 3and 5 % for AD201 and Serw4, respectively, but at these harvest dates, the seed yield was increased by 3 % for Pactol compared to 150 DAP (Table 9). In the same time, effect of cultivar × harvesting date interactions was not significant for the number of pods per plant, number of seeds per pod, thousand seed weight and seed moisture content, but it seems that pod number per plant was the nearest character to significance more than those as P values were equals 0.06, 0.08, 0.24 and 0.81respectively (Tables7, 9).With delaying the harvest at 157, 163 DAP, pod number per plant was increased by 1, 2 and 3 % for AD201, Serw4 and Pactol, respectively compared to harvesting at 150 DAP (Table 7).Thus,the reduction in the seed yield for AD201 and Serw4 cultivars with delaying the harvest was mainly related to pod shattering.Meanwhile, the increasing in seed yield for Pactol at these dates may be partially related to producing little more pods, but the major reason may be related to the ability of Pactolto resisting pod shattering compared to either AD201 or Serw4. Hence, these previous results may be taken into consideration as indicators of the variability of cultivars in the sensitivity of pods to shattering, which may help plant breeders to produce resistance plants to pod shattering and maximizing the production efficiency.

There was a significant effect of plant density × harvesting date interactions on the seed yield(Table 9) and this was greatly consistent with pods number per plant. At 7.1 plants m^{-2}, the highest seed yield was recorded with earlyharvesting at 150, 157 DAP and higher than harvesting at 163 DAP by 2%, also at 9.5 plants m^{-2}, the early harvesting at 150 DAP recorded the higher yield than 157, 163 DAP by 6 %, whereas harvesting too late at 163 DAP for plant density of 11.9 plants m^{-2}, exhibited a higher yield by 7% more than the early two harvesting dates.

Harvest index

Harvest index was affected significantly by all main factors and interactions (Table 11). Significant impact of cultivar, plant density and their interaction was also observed by (Shrief, 1989). The magnitude differences for harvest index within interactions which included cultivar were more than the others which have not included cultivar. For instance, all harvest index means for either cultivar × plant density and/or cultivar × harvest time interactions, were fall within about 10% range whereas it were about 4% within plant density × harvest time interaction. Also the significant variability in harvest index values within cultivars was more than other main factors – plant density and harvest time; it reached averaged 10, 5 and 3 %, respectively. Consequently, in this research, I may infer that varying cultivars seemed to be a limiting factor for the harvest index.

On the other side, highest harvest index was achieved by 9.5 plants m^{-2} as 47 % and higher than 7.1, 11.9 plants m^{-2} by 3.6 and 4.6 %, respectively (Table 12). These results were contrast to the results of Angadi, (2003) as he found that under good growing conditions the harvest index was stable across range from 5 to 10 to 80 plants m^{-2}. Under the circumstances of this research, I found that decreasing harvest index suggests that the extra assimilate (straw yield) invested by plant density of 7.1 and 11.9 plants m^{-2} in vegetative structures such as plant height, primary and secondary branches was negatively affect the seed weight per plant compared to plant density of 9.5 plants m^{-2}.

Oil % and oil yield per faddan.

Oil percentage was affected only by cultivar (Table 11). Cultivar has been reported to affect the oil percentage of canola plants by (Shrief, 1989; Harker et al., 2003; Ozer, 2003; Chen et al., 2005), but not in the studies of (Johnson and Hanson, 2003; Lamb and Johnson, 2004; Chen et al., 2005). Highest oil percentage was observed forPactol as approximately 38% and differed significantly from that of Serw4 which was approximately 37%, whereas the lowest oil percentage (36.5%) was observed at AD201 (Table 12). Similar to findings of Taha, (2001), who found that Pactol variety displayed higher oil percentage as 37.6% compared to AD201 which was 36.2%.

Neither plant density nor harvesting date or any interactions had any impact on oil percentage (Table 11). Similar to findings of (Dosdall et al., 1996; Harker et al., 2003; Morrison et al., 1990) as a wide range of densities had no significant effect on the oil percentage. In addition, Taha, (2007) found no difference among three densities in oil percentage of Serw4 cultivar which approximately averaged 37%. However, Chen et al., (2005) found significant impact of plant density on the oil percentage. Based on results of Harker et al., 2003 and Chen et al., 2005, the oil percentage was not affected by cultivar × plant density interactions. Taha, (2007) found no differences in the oil percentage (averaged 37.5%) at three harvesting date for Serw4 cultivar.

Both of cultivar, plant density and their interactions had a significance effect on the oil yield (Table 11). Table 11 showed also that all oil yield means for cultivar × plant density interaction fall within about 19% range (346 kg fad^{-1} for Serw4 × 9.5 plants m^{-2}vs 427 kg fad^{-1} for Pactol × 9.5 plants m^{-2}). Although, highest seed yield (1077 kg fad^{-1}) was observed at AD201, but highest oil yield (397 kg fad^{-1}) was achieved by Pactol variety and exceeded AD201 by 1 % due to the differences in oil %, and also exceeded Serw4 by approximately 7.5 %. Similar to findings based on Taha’ data (2001) as oil yield for Pactol exceeded Ad201 by approximately 7%. In addition, according to the data of Taha, (2007), the oil yield for Serw4 averaged 384 kg fad^{-1} across plant densities. Based on data of (Harker et al., 2003; Johnson and Hanson, 2003; Ozer, 2003; Lamb and Johnson, 2004; Chen et al., 2005) the oil yield differed between cultivars by 4 to 29 %, with respect to cultivars, oil %, seed yield, environmental conditions. On the other side, in this research, achieving high oil yield (384 kg fad^{-1}) was obtained by 9.5 plants m^{-2} and higher than 7.1 and 11.9 plants m^{-2} by approximately 3 and 6 %, respectively. Based on data of Taha (2007), the differences within three plant densities in oil yield were less than 2.5 %.

Both of cultivar × harvesting date and plant density × harvesting date interactions had significant impact on oil yield while harvesting date did not significantly affect oil yield (Table 11). Taha (2007) found also no significant effect of harvesting date on oil yield which averaged 386 kg fad^{-1} for Serw4. Table 11 also showed that all oil yield means for either cultivar × harvesting date and/or plant density × harvesting date interactions were fall within about 13% range.

Table 11. Analysis of variance (P values) and effect of the possible two-way interactions between cultivars, plant densities and harvest time on straw yield, harvest index, oil percentage and oil yield, adjusted means were averaged over 2007 and 2008 seasons.

Cultivar	**Actual plant density**	**Harvest Time†**	**Straw yield**	**Harvest index**	**Oil**	**Oil yield**
	no. m^{-2}	—— d ——	Kg fad^{-1}	——— %	———	Kg fad^{-1}
			Tow-way interactions			
	7.1	-	1215.27	46.05	36.64	377.94
AD201	9.5	-	1026.38	53.10	36.47	422.99
	11.9	-	1144.44	47.72	36.59	378.73
	7.1	-	1273.61	44.77	38.05	393.23
Pactol	9.5	-	1284.72	46.57	38.13	426.87
	11.9	-	1264.16	43.41	38.03	370.71
	7.1	-	1223.61	46.06	37.14	385.67
Serw4	9.5	-	1263.88	42.37	37.11	345.66

	11.9	-	1256.94	44.40	37.01	371.78
					NS	
	-	150	1038.88	51.61	36.41	401.07
AD201	-	157	1212.49	47.16	36.54	396.31
	-	163	1134.72	48.11	36.58	382.28
	-	150	1270.83	44.39	38.08	387.94
Pactol	-	157	1287.49	45.02	38.15	403.02
	-	163	1264.16	45.33	37.98	399.85
	-	150	1309.72	43.88	37.01	379.94
Serw4	-	157	1247.22	43.42	37.14	355.66
	-	163	1187.50	45.54	37.11	367.52
					NS	
		150	1240.27	45.60	37.19	385.91
-	7.1	157	1295.83	44.57	37.22	389.20
		163	1176.38	46.71	37.25	381.74
		150	1180.55	48.71	37.11	414.04
-	9.5	157	1240.27	46.66	37.36	405.79
		163	1154.16	46.67	37.24	375.69
		150	1198.61	45.57	37.20	369.00
-	11.9	157	1211.11	44.37	37.25	360.00
		163	1255.83	45.59	37.18	392.22
					NS	
SE			16.417	0.413	0.083	4.800

	ANOVA			
Source of variation	P values			
Replication	0.7957	0.0001	0.0083	0.0001
Blocks/ rep	0.5332	0.2261	0.4883	0.7801
Cultivar (C)	0.0001	0.0001	0.0001	0.0001
Plant density (P)	0.0038	0.0001	0.9041	0.0001
Harvesting date (H)	0.0004	0.0002	0.2695	0.2447

C × P	0.0001	0.0001	0.4702	0.0001
C × H	0.0001	0.0001	0.5503	0.0004
P × H	0.0001	0.0067	0.6184	0.0001
C × P × H	0.0001	0.0001	0.4563	0.0001

† Harvest at 150, 157 and 163 DAP.

Table 12. The main effects of the cultivars, plant densities and harvest time for straw yield, harvest index, oil percentage and oil yield, adjusted means were averaged over 2007 and 2008 seasons.

Main effect	**Straw yield**	**Harvest index**	**Oil**	**Oil yield**
	— kg fad^{-1} —	——— % ———		— kg fad^{-1} —
Cultivar				
AD201	1128.70	48.96	36.51	393.22
Pactol	1274.16	44.91	38.07	396.94
Serw4	1248.14	44.28	37.09	367.71
Plant density / m^{-2}				
7.1	1237.49	45.63	37.22	385.61
9.5	1191.66	47.35	37.24	398.51
11.9	1221.85	45.18	37.21	373.74
			NS	
Harvest date†				

150	1206.48	46.63	37.16	389.65
157	1249.07	45.20	37.28	385.00
163	1195.46	46.33	37.22	383.22
			NS	NS
SE	9.478	0.238	0.048	2.771

† Harvest at 150, 157 and 163 DAP.

SUMMARY AND CONCLUSIONS

By using a confounded design, the reduction in number of plots per complete block to one-third per incomplete block was not as efficient as it should be regarding treatment precision. Unless soil fertility gradient is multidirectional to be accounted for by reducing block size, incomplete block orientation may seem to be a limiting factor. Due to field requirementfor designing surface irrigation, watering pathways and inter-tier borders are present. The occurrence of many of these natural barriers between plots within a block present a likely negative impact on block homogeneity if they run perpendicular to the direction of each block since they affect adjacent plots within the same incomplete block. In addition, relative to the sod growth pattern as the case in forage crops, the growth nature of the canola crop, as individual branching plants, may influence plot to plot variation regarding final plant count if missing hills is experienced. Therefore, in future experiments, confounded designs need to be applied to cover crops, in which incomplete blocks be laid out parallel to natural barriers or fit spatial analyses models to account for more complicated soil variations.

Both canola plant density per unit area and cultivar are critical factors in maximizing seed yield. These two factors effects on canola seed yield seem to be affecting the ability of plant to produce more pods with higher seed weight. Although results showed that achieving high seed yield was obtained by plant density of 9.5 plants m^{-2} compared to 7.1 and 11.9 plants m^{-2}, it is necessary to study a wide range of plant density in relation to canola yield. On the other hand, since harvest time did not play a significance role for maximizing canola yield in this trial, this may differ if there are more varied planting dates.

APPENDICES

Table 1. Analysis of variance (P values) and effect of the possible two-way interactions between cultivars, plant densities and harvest time on plant height, number of primary, secondary and total branches in 2007.

Cultivar	Actual plant density	Harvest time†	Plant height	Branch plant^{-1}		
				Primary	Secondary	Total
	no. m^{-2}	— d —	— cm —			
			Tow-way interactions			
	7.1	-	149	7.79	16.56	24.35
AD201	9.5	-	146.38	7.62	13.36	20.99
	11.9	-	151.39	8.10	13.05	21.15
	7.1	-	148.02	8.80	15.76	24.56
Pactol	9.5	-	144.70	7.70	15.30	23
	11.9	-	142.83	7.29	14.05	21.34
	7.1	-	149.01	8.16	16.25	24.42
Serw4	9.5	-	146.90	7.90	14.58	22.48
	11.9	-	147.43	7.49	12.38	19.87
			NS	NS	NS	NS
	-	150	149.15	7.51	14.64	22.15
AD201	-	157	145.53	7.66	13.43	21.10
	-	163	152.08	8.33	14.90	23.24
	-	150	149.83	8.25	15.65	23.90
Pactol	-	157	141	7.20	13.03	20.23
	-	163	145.16	8.34	16.43	24.77
	-	150	150.51	7.75	15.63	23.38
Serw4	-	157	142.58	7.28	12.30	19.58
	-	163	150.25	8.52	15.29	23.81
			NS	NS	NS	NS

		150	152.33	8.30	17.58	25.88
-	7.1	157	145.20	7.50	14.25	21.75
		163	148.50	8.95	16.75	25.71
		150	146.15	7.81	14.70	22.51
-	9.5	157	142.83	7.40	13.21	20.61
		163	149.00	8.00	15.33	23.34
		150	150.57	7.40	13.64	21.04
-	11.9	157	141.08	7.25	11.30	18.55
		163	150	8.23	14.54	22.77
			NS	NS	NS	NS
SE			1.923	0.315	0.810	1.043
				ANOVA		
Source of variation			P values			
Replication			0.1528	0.7298	0.2306	0.4627
Blocks/ rep			0.6712	0.7014	0.8070	0.8264
Cultivar (C)			0.0574	0.9292	0.5041	0.5909
Plant density (P)			0.2376	0.0413	0.0001	0.0002
Harvesting date (H)			0.0001	0.0009	0.0002	0.0001
C × P			0.3128	0.0715	0.3932	0.7133
C × H			0.3970	0.3941	0.6376	0.6334
P × H			0.2796	0.6176	0.7224	0.7783
C × P × H			0.4636	0.8999	0.0902	0.2144

† Harvest at 150, 157 and 163 DAP.

Table 2. The main effects of the cultivars, plant densities and harvest time for plant height, number of primary, secondary and total branches in 2007.

		Branch plant^{-1}		
Main effect	**Plant height**	**Primary**	**Secondary**	**Total**
	— cm —			
Cultivar				
AD201	148.92	7.83	14.32	22.16

Pactol	145.18	7.93	15.03	22.96
Serw4	147.78	7.85	14.40	22.26
		NS	NS	NS
Plant density / m^{-2}				
7.1	148.68	8.25	16.19	24.45
9.5	145.99	7.74	14.41	22.15
11.9	147.21	7.62	13.16	20.78
	NS			
Harvest date†				
150	149.68	7.83	15.30	23.14
157	143.04	7.38	12.92	20.30
163	149.16	8.40	15.54	23.94
SE	1.110	0.182	0.468	0.602

† Harvest at 150, 157 and 163 DAP.

Table 3. Analysis of variance (P values) and effect of the possible two-way interactions between cultivars, plant densities and harvest time on pods per plant, number of seeds per pod, pod weight per plant and thousand seed weight in 2007.

Cultivar	**Actual Plant density**	**Harvest time†**	**Pods plant^{-1}**	**Seeds pod^{-1}**	**Pods wt plant^{-1}**	**1000 seed wt**
	— no. m^{-2} —	— d —			——— g ———	
			Tow-way interactions			
AD201	7.1	-	475.65	26.05	58.49	3.56
	9.5	-	408.45	23.52	43.15	3.49
	11.9	-	383.58	24.55	42.02	3.47
Pactol	7.1	-	411.40	23.10	56.63	3.65
	9.5	-	412.33	23.87	53.46	3.89
	11.9	-	382.69	23.95	47.69	3.68
Serw4	7.1	-	386.20	23.84	45.64	3.75
	9.5	-	381.10	22.90	51.04	3.90
	11.9	-	336.86	23.83	42.51	3.69
				NS		NS

AD201	-	150	428.40	25	57.54	3.62
	-	157	410.26	24.72	55.93	3.59
	-	163	429.02	24.40	30.19	3.31
Pactol	-	150	376.15	24.40	71.01	3.77
	-	157	385.15	23.75	53.78	3.77
	-	163	445.12	22.78	32.99	3.68
Serw4	-	150	354.20	23.47	57.02	3.72
	-	157	375.07	24.86	47.30	3.91
	-	163	374.89	22.24	34.87	3.72
				NS		NS
-	7.1	150	436.24	24.40	66.82	3.54
		157	388.40	23.52	60.03	3.84
		163	448.61	25.08	33.91	3.57
-	9.5	150	371.95	24.52	63.68	3.93
		157	402.44	24.01	48.83	3.79
		163	427.49	21.76	35.14	3.56
-	11.9	150	350.57	23.95	55.07	3.63
		157	379.64	25.80	48.15	3.64
		163	372.92	22.57	29	3.58
					NS	
SE			10.115	0.858	2.745	0.084

Source of variation	ANOVA P values			
Replication	0.0137	0.0314	0.0024	0.0001
Blocks/ rep	0.0390	0.7191	0.3094	0.8574
Cultivar (C)	0.0001	0.1855	0.0195	0.0003
Plant density (P)	0.0001	0.4138	0.0003	0.0947
Harvesting date (H)	0.0008	0.1330	0.0001	0.0289
C × P	0.0043	0.4149	0.0086	0.4332
C × H	0.0042	0.6342	0.0075	0.3522
P × H	0.0004	0.0422	0.1857	0.0402

C × P × H	0.0001	0.1022	0.5316	0.4766

† Harvest at 150, 157 and 163 DAP.

Table 4. The main effects of the cultivars, plant densities and harvest time for pods per plant, number of seeds per pod, pod weight per plant and thousand seed weight in 2007.

Main effect	**Pods plant^{-1}**	**Seeds pod^{-1}**	**Pod wt plant^{-1}**	**1000 seed wt**
			——— g ———	
Cultivar				
AD201	422.56	24.71	47.89	3.51
Pactol	402.14	23.64	52.60	3.74
Serw4	368.05	23.52	46.40	3.78
		NS		
Plant density / m^{-2}				
7.1	424.42	24.33	53.59	3.65
9.5	400.62	23.43	49.22	3.76
11.9	367.71	24.11	44.07	3.62
		NS		NS
Harvest date†				
150	386.25	24.29	61.86	3.70

157	390.16	24.45	52.34	3.76
163	416.34	23.14	32.68	3.57
		NS		
SE	5.839	0.495	1.584	0.048

† Harvest at 150, 157 and 163 DAP.

Table 5. Analysis of variance (P values) and effect of the possible two-way interactions between cultivars, plant densities and harvest time on seed yield, straw yield, harvest index and seed weight per plant in 2007.

Cultivar	**Actual plant density**	**Harvest time†**	**Seed wt plant^{-1}**	**Seed yield**	**Straw yield**	**Harvest index**
	no. m^{-2}	—— d ——	— g —	——— Kg fad^{-1} ———		**— % —**
				Tow-way interactions		

AD201	7.1	-	22.13	1042.52	1266.66	45.16
	9.5	-	16.82	1179.83	1080.55	52.15
	11.9	-	15.37	1062.15	1155.55	47.94
Pactol	7.1	-	18.64	1044.12	1286.11	44.75
	9.5	-	18.80	1141.70	1261.11	47.50
	11.9	-	16.47	977.87	1258.33	43.53
Serw4	7.1	-	13.78	1057.21	1247.22	45.95
	9.5	-	16.79	911.68	1280.55	41.54
	11.9	-	15.60	988.00	1263.88	43.95
AD201	-	150	20.71	1127.02	1122.22	50.15
	-	157	17.51	1093.00	1227.77	47.01
	-	163	16.10	1064.46	1152.77	48.08
Pactol	-	150	18.44	1028.17	1280.55	44.38
	-	157	17.64	1079.47	1272.22	45.84
	-	163	17.83	1056.05	1252.77	45.56
Serw4	-	150	15.11	1002.05	1324.99	43.00
	-	157	16.68	958.74	1244.44	43.56
	-	163	14.38	996.09	1222.22	44.88
-	7.1	150	17.41	1049.81	1294.44	44.76
		157	19.78	1047.35	1297.22	44.61
		163	17.37	1046.68	1208.33	46.48
-	9.5	150	20.61	1116.43	1211.11	47.87
		157	16.93	1112.58	1241.66	47.18
		163	14.86	1004.19	1169.44	46.15
-	11.9	150	16.24	991.00	1222.22	44.90
		157	15.12	971.28	1205.55	44.63
		163	16.08	1065.74	1250.00	45.89
SE			0.737	13.499	20.133	0.509

	ANOVA			
	P values			
Replication	0.0675	0.0008	0.6149	0.0947
Blocks/ rep	0.1747	0.7779	0.3816	0.1459
Cultivar (C)	0.0001	0.0001	0.0001	0.0001
Plant density (P)	0.0006	0.0001	0.0020	0.0001
Harvesting date (H)	0.0061	0.4646	0.0437	0.2473
C × P	0.0001	0.0001	0.0001	0.0001
C × H	0.0073	0.0006	0.0004	0.0001
P × H	0.0001	0.0001	0.0080	0.0095
C × P × H	0.0001	0.0001	0.0008	0.0001

† Harvest at 150, 157 and 163 DAP.

Table 6. The main effects of the cultivars, plant densities and harvest time for seed yield, straw yield, harvest index, seed weight per plant in 2007.

Main effect	**Seed wt plant^{-1}**	**Seed yield**	**Straw yield**	**Harvest index**
	g	kg fad^{-1}		**%**
Cultivar				
AD201	18.11	1094.83	1167.59	48.42
Pactol	17.97	1054.56	1268.51	45.26
Serw4	15.39	985.63	1263.88	43.81
Plant density / m^{-2}				

7.1	18.19	1047.95	1266.66	45.28
9.5	17.47	1077.73	1207.40	47.06
11.9	15.81	1009.34	1225.92	45.14
Harvest date†				
150	18.09	1052.41	1242.59	45.84
157	17.27	1043.74	1248.14	45.47
163	16.10	1038.87	1209.25	46.17
		NS		NS
SE	0.425	7.793	11.624	0.294

† Harvest at 150, 157 and 163 DAP.

Table 7. Analysis of variance (P values) and effect of the possible two-way interactions between cultivars, plant densities and harvest time on seed moisture content, oil percentage and oil yield in 2007.

Cultivar	**Actual plant density**	**Harvest time†**	**SMC‡**	**Oil**	**Oil yield**
	— no. m^{-2} —	— d —	— **%** —		Kg fad^{-1}
			Tow-way interactions		
	7.1	-	12.20	36.12	376.66
AD201	9.5	-	12.07	36.17	426.73
	11.9	-	12.49	36.23	384.72
	7.1	-	11.96	37.78	394.49
Pactol	9.5	-	12.22	38.08	434.86
	11.9	-	12.28	37.85	370.06
	7.1	-	12.03	36.86	389.67
Serw4	9.5	-	12.24	36.78	335.46
	11.9	-	12.30	36.89	364.66
			NS	NS	
	-	150	13.16	36.05	406.29
AD201	-	157	12.71	36.23	395.95
	-	163	10.88	36.25	385.87
	-	150	13.05	37.87	389.53
Pactol	-	157	12.71	37.98	410.11
	-	163	10.70	37.85	399.76
	-	150	13.21	36.69	367.95
Serw4	-	157	12.39	36.85	353.39
	-	163	10.97	36.99	368.45
			NS	NS	

-	7.1	150	13.19	36.84	386.59
		157	12.45	36.96	387.46
		163	10.55	36.96	386.77
-	9.5	150	13.18	36.78	411.29
		157	12.52	37.23	413.87
		163	10.83	37.01	371.89
-	11.9	150	13.05	36.98	365.89
		157	12.84	36.87	358.12
		163	11.18	37.11	395.42
			NS	NS	
SE			0.206	0.129	5.357

Source of variation	ANOVA		
	——————— P values ———————		
Replication	0.1435	0.4104	0.0048
Blocks/ rep	0.3090	0.2148	0.6663
Cultivar (C)	0.8438	0.0001	0.0001
Plant density (P)	0.2186	0.6919	0.0001
Harvesting date (H)	0.0001	0.2374	0.7613
C × P	0.8531	0.5748	0.0001
C × H	0.6427	0.7757	0.0018
P × H	0.4330	0.2569	0.0001
C × P × H	0.4429	0.7502	0.0001

† Harvest at 150, 157 and 163 DAP.

‡ Seed moisture content.

Table 8. The main effects of the cultivars, plant densities and harvest time for seed moisture content, oil percentage and oil yield in 2007.

Main effect	**SMC‡**	**Oil**	**Oil yield**
	———— **%** ————		—— kg fad^{-1} ——

Cultivar			
AD201	12.25	36.17	396.04
Pactol	12.15	37.90	399.80
Serw4	12.19	36.84	363.26
	NS		
Plant density / m^{-2}			
7.1	12.06	36.92	386.94
9.5	12.18	37.01	399.02
11.9	12.36	36.99	373.14
	NS	NS	
Harvest date†			
150	13.14	36.87	387.92
157	12.60	37.02	386.48
163	10.85	37.03	384.69
		NS	NS
SE	0.119	0.074	3.093

† Harvest at 150, 157 and 163 DAP.

‡ Seed moisture content.

Table 9. Analysis of variance (P values) and effect of the possible two-way interactions between cultivars, plant densities and harvest time on plant height, number of primary, secondary and total branches in 2008.

Cultivar	Actual plant density	Harvest time†	Plant height	Branch plant^{-1}		
				Primary	**Secondary**	**Total**
	no. m^{-2}	—— d ——	— cm —			
			Tow-way interactions			
	7.1	-	148.16	7.77	16.80	24.58
AD201	9.5	-	147.17	7.80	17.51	25.32
	11.9	-	159.25	8.11	16.55	24.66
	7.1	-	143.66	8.90	15.52	24.43
Pactol	9.5	-	144.75	7.76	16.58	24.35
	11.9	-	149.08	7.76	18.65	26.41
	7.1	-	153.70	8.15	16.97	25.12
Serw4	9.5	-	146.75	8.33	18.33	26.66

	11.9	-	149.25	7.87	15.22	23.10
				NS		
	-	150	147.30	7.77	15.81	23.59
AD201	-	157	151.65	7.61	17.17	24.79
	-	163	155.62	8.30	17.88	26.19
	-	150	144.75	8.44	16.57	25.01
Pactol	-	157	145.16	7.50	17.07	24.57
	-	163	147.58	8.50	17.10	25.60
	-	150	147.48	7.95	15.88	23.84
Serw4	-	157	150.05	7.79	16.95	24.74
	-	163	152.16	8.60	17.70	26.30
			NS	NS	NS	NS
		150	145.77	8.43	15.85	24.28
-	7.1	157	148.59	7.45	16.57	24.03
		163	151.16	8.94	16.88	25.82
		150	144.35	8.05	17.33	25.38
-	9.5	157	145.53	7.75	17.43	25.18
		163	148.79	8.10	17.66	25.77
		150	149.41	7.69	15.09	22.78
-	11.9	157	152.75	7.70	17.19	24.89
		163	155.41	8.36	18.14	26.50
			NS	NS	NS	NS
SE			1.003	0.345	0.542	0.682

	ANOVA			
Source of variation	P values			
Replication	0.1286	0.8099	0.8470	0.8344
Blocks/ rep	0.9522	0.5935	0.8815	0.6863
Cultivar (C)	0.0001	0.6342	0.9664	0.9325
Plant density (P)	0.0001	0.3928	0.0649	0.3275

Harvesting date (H)	0.0001	0.0159	0.0050	0.0037
C × P	0.0001	0.1555	0.0001	0.0026
C × H	0.0908	0.7695	0.6754	0.5600
P × H	0.8546	0.4308	0.1365	0.1333
C × P × H	0.9197	0.8592	0.0637	0.1806

† Harvest at after 150, 157 and 163 DAP.

Table 10. The main effects of the cultivars, plant densities and harvest time for plant height, number of primary, secondary and total branches in 2008.

		Branch plant^{-1}		
Main effect	**Plant height**	**Primary**	**Secondary**	**Total**
	— cm —			
Cultivar				
AD201	151.53	7.90	16.95	24.85
Pactol	145.83	8.14	16.91	25.06
Serw4	149.90	8.11	16.84	24.96
		NS	NS	NS
Plant density / m^{-2}				
7.1	148.51	8.27	16.43	24.71
9.5	146.22	7.96	17.47	25.44
11.9	152.52	7.91	16.80	24.72
		NS	NS	NS
Harvest date†				

150	146.51	8.05	16.09	24.15
157	148.95	7.63	17.06	24.70
163	151.79	8.47	17.56	26.03
SE	0.579	0.199	0.312	0.393

† Harvest at after 150, 157 and 163 DAP.

Table 11. Analysis of variance (P values) and effect of the possible two-way interactions between cultivars, plant densities and harvest time on pods per plant, number of seeds per pod, pod weight per plant and thousand seed weight in 2008.

Cultivar	Actual	Harvest	Pods	Seeds	Pods	1000

	Plant density	time†	plant^{-1}	pod^{-1}	wt plant^{-1}	seed wt
	— no. m^{-2} —	—— d ——			———— g ————	—
			Tow-way interactions			
AD201	7.1	-	354.13	26.28	56.32	3.60
	9.5	-	442.19	23.99	45.45	3.91
	11.9	-	497.84	24.87	45.92	3.71
Pactol	7.1	-	466.55	25.28	53.51	3.88
	9.5	-	404.66	25.17	48.04	4.11
	11.9	-	435.96	24.50	46.08	3.75
Serw4	7.1	-	412.26	24.05	47.66	3.85
	9.5	-	380.03	22.29	49.53	3.98
	11.9	-	450.44	24.59	40.30	3.71
				NS		NS
AD201	-	150	419.65	25.40	61.02	3.80
	-	157	443.04	25.27	53.24	3.73
	-	163	431.46	24.46	33.43	3.69
Pactol	-	150	446.47	26.68	59.60	3.85
	-	157	425.06	23.49	54.41	4.02
	-	163	435.64	24.79	33.63	3.85
Serw4	-	150	437.94	24.88	57.21	3.69
	-	157	402.29	25.02	48.74	3.97
	-	163	402.50	21.03	31.54	3.87
			NS		NS	NS
-	7.1	150	444.29	25.49	62.63	3.62
		157	389.25	23.40	58.31	3.96
		163	399.40	26.72	36.56	3.74
-	9.5	150	408.64	25.15	59.07	4.01
		157	423.90	24.46	49.47	3.95
		163	394.34	21.83	34.48	4.03

		150	451.15	26.32	56.12	3.71
-	11.9	157	457.24	25.91	48.62	3.81
		163	475.86	21.73	27.57	3.65
					NS	NS
SE			11.494	0.709	2.001	0.076

	ANOVA			
Source of variation	P values			
Replication	0.4391	0.4889	0.8143	0.4041
Blocks/ rep	0.3397	0.9983	0.3994	0.8387
Cultivar (C)	0.0600	0.0284	0.0632	0.0286
Plant density (P)	0.0001	0.0607	0.0001	0.0001
Harvesting date (H)	0.3815	0.0012	0.0001	0.1075
C × P	0.0001	0.2162	0.0285	0.3706
C × H	0.0957	0.0041	0.8699	0.1553
P × H	0.0041	0.0001	0.3947	0.0915
C × P × H	0.0001	0.2839	0.0013	0.2748

† Harvest at after 150, 157 and 163 DAP.

Table 12. The main effects of the cultivars, plant densities and harvest time for pods per plant, number of seeds per pod, pod weight per plant and thousand seed weight in 2008.

Main effect	**Pods plant^{-1}**	**Seeds pod^{-1}**	**Pod wt plant^{-1}**	**1000 seed wt**
			g	
Cultivar				
AD201	431.38	25.05	49.23	3.74
Pactol	435.72	24.98	49.21	3.91

Serw4	414.24	23.64	45.83	3.85
	NS		NS	
Plant density / m^{-2}				
7.1	410.98	25.20	52.50	3.78
9.5	408.96	23.81	47.67	4.00
11.9	461.41	24.65	44.10	3.72
		NS		
Harvest date†				
150	434.69	25.65	59.27	3.78
157	423.46	24.59	52.13	3.91
163	423.20	23.43	32.87	3.81
	NS			NS
SE	6.636	0.409	1.155	0.044

† Harvest at after 150, 157 and 163 DAP.

Table 13. Analysis of variance (P values) and effect of the possible two-way interactions between cultivars, plant densities and harvest time on seed yield, straw yield, harvest index and seed weight per plant in 2008.

Cultivar	Actual plant density	Harvest time†	Seed wt plant^{-1}	Seed yield	Straw yield	Harvest index
	no. m^{-2}	—— d ——	— g —	——— Kg fad^{-1} ———		— % —
			Tow-way interactions			
	7.1	-	17.87	1030.67	1163.88	46.95
AD201	9.5	-	19.59	1139.91	972.22	54.05
	11.9	-	17.61	1007.88	1133.33	47.51
	7.1	-	17.35	1022.58	1261.11	44.79
Pactol	9.5	-	21.77	1097.04	1308.33	45.63
	11.9	-	16.36	972.36	1270.00	43.28
	7.1	-	15.05	1019.50	1200.00	46.18
Serw4	9.5	-	18.61	950.65	1247.22	43.20
	11.9	-	14.95	1020.18	1249.99	44.86
			NS			
	-	150	18.61	1076.32	955.55	53.07
AD201	-	157	19.06	1076.50	1197.22	47.30
	-	163	17.39	1025.64	1116.66	48.13
	-	150	20.03	1008.99	1261.11	44.40
Pactol	-	157	18.89	1033.31	1302.77	44.19

	-	163	16.56	1049.68	1275.55	45.10
	-	150	15.39	1049.94	1294.44	44.75
Serw4	-	157	14.50	955.87	1249.99	43.28
	-	163	18.73	984.52	1152.77	46.20
		150	16.34	1026.11	1186.11	46.44
-	7.1	157	16.05	1042.95	1294.44	44.53
		163	17.89	1003.70	1144.44	46.94
		150	20.87	1113.90	1150.00	49.55
-	9.5	157	20.58	1061.14	1238.88	46.14
		163	18.52	1012.56	1138.88	47.20
		150	16.82	995.24	1175.00	46.24
-	11.9	157	15.83	961.59	1216.66	44.11
		163	16.27	1043.60	1261.66	45.30
						NS
SE			0.674	15.398	24.072	0.609

	ANOVA			
Source of variation	P values			
Replication	0.3419	0.0001	0.9476	0.0005
Blocks/ rep	0.1860	0.5435	0.8960	0.9448
Cultivar (C)	0.0001	0.0001	0.0001	0.0001
Plant density (P)	0.0001	0.0001	0.0898	0.0001
Harvesting date (H)	0.5901	0.0916	0.0002	0.0001
C × P	0.1273	0.0001	0.0001	0.0001
C × H	0.0001	0.0002	0.0001	0.0001
P × H	0.0280	0.0001	0.0024	0.2250
C × P × H	0.0017	0.0001	0.0001	0.0001

† Harvest at after 150, 157 and 163 DAP.

Table 14. The main effects of the cultivars, plant densities and harvest time for seed yield, straw yield, harvest index and seed weight per plant in 2008.

Main effect	**Seed wt plant^{-1}**	**Seed yield**	**Straw yield**	**Harvest index**
	—— g ——	———— kg fad^{-1} ————		—— % ——
Cultivar				
AD201	18.36	1059.49	1089.81	49.50
Pactol	18.49	1030.66	1279.81	44.57
Serw4	16.20	996.78	1232.40	44.75
Plant density / m^{-2}				
7.1	16.76	1024.25	1208.33	45.97
9.5	19.99	1062.53	1175.92	47.63
11.9	16.31	1000.14	1217.77	45.21
			NS	
Harvest date†				
150	18.01	1045.08	1170.37	47.41
157	17.48	1021.90	1249.99	44.93
163	17.56	1019.95	1181.66	46.48
	NS	NS		

SE	0.389	8.890	13.897	0.351

† Harvest at after 150, 157 and 163 DAP.

Table 15. Analysis of variance (P values) and effect of the possible two-way interactions between cultivars, plant densities and harvest time on seed moisture content, oil percentage and oil yield in 2008.

Cultivar	**Actual plant density**	**Harvest time†**	**SMC‡**	**Oil**	**Oil yield**
	— no. m^{-2} —	— d —	——— % ———		— Kg fad^{-1} —
				Tow-way interactions	
	7.1	-	12.30	36.79	379.14
AD201	9.5	-	12.10	36.78	419.12
	11.9	-	12.05	36.96	372.57

Pactol	7.1	-	12.45	38.33	391.91
	9.5	-	12.20	38.19	418.93
	11.9	-	12.25	38.20	371.29
Serw4	7.1	-	12.29	37.42	381.57
	9.5	-	12.05	37.44	356.02
	11.9	-	12.25	37.13	378.97
			NS	NS	
AD201	-	150	12.94	36.77	395.64
	-	157	12.50	36.85	396.64
	-	163	11.01	36.91	378.55
Pactol	-	150	13.23	38.29	386.34
	-	157	12.69	38.31	395.93
	-	163	10.99	38.11	399.86
Serw4	-	150	13.22	37.33	392.06
	-	157	12.82	37.44	357.90
	-	163	10.55	37.23	366.59
			NS	NS	
-	7.1	150	13.09	37.54	385.09
		157	12.71	37.48	390.94
		163	11.24	37.53	376.59
-	9.5	150	13.15	37.43	416.90
		157	12.60	37.50	397.69
		163	10.60	37.48	379.48
-	11.9	150	13.15	37.42	372.07
		157	12.69	37.63	361.83
		163	10.70	37.24	388.93
			NS	NS	
SE			0.154	0.096	5.885

	ANOVA
Source of variation	P values

Replication	0.0366	0.0013	0.0001
Blocks/ rep	0.3484	0.1638	0.6398
Cultivar (C)	0.4686	0.0001	0.0001
Plant density (P)	0.1850	0.5583	0.0001
Harvesting date (H)	0.0001	0.3419	0.1084
C × P	0.9427	0.0776	0.0001
C × H	0.0792	0.4321	0.0006
P × H	0.1715	0.1906	0.0001
C × P × H	0.3197	0.5825	0.0001

† Harvest at after 150, 157 and 163 DAP.

‡ Seed moisture content.

Table 16. The main effects of the cultivars, plant densities and harvest time for seed moisture content, oil percentage and oil yield in 2008.

Main effect	**SMC‡**	**Oil**	**Oil yield**
	———— **%** ————		—— kg fad^{-1} ——
Cultivar			
AD201	12.15	36.84	390.28
Pactol	12.30	38.24	394.04
Serw4	12.20	37.33	372.19
	NS		
Plant density / m^{-2}			
7.1	12.35	37.51	384.21
9.5	12.12	37.47	398.02

11.9	12.18 NS	37.43 NS	374.27
Harvest date†			
150	13.13	37.46	391.35
157	12.67	37.53	383.49
163	10.85	37.42 NS	381.67 NS
SE	0.089	0.055	3.398

† Harvest at after 150, 157 and 163 DAP.

‡ Seed moisture content.

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الملخص

في تجربة عاملية $٣^٣$ حقلية لنبات الكانولا *Brassica napus* L.، تم تطبيق ظاهرة الإدماج الكامل لتأثير التفاعل الثلاثي مع تأثير القطاعات الغير كاملة لتقليص حجم القطاع الكامل من ٢٧ قطعة تجريبية إلي فقط ٩ قطع تجريبية. هذا حيث يهدف الإدماج، عموماً، إلي زيادة دقة المقارنة بين المعاملات المختلفة بتقليل إحتمال زيادة الأخطاء التجريبية من خلال التمكن أكثر من السيطرة علي العوامل التي تؤدي، عادة، إلي زيادة الإختلافات البينية فيما بين القطع التجريبية داخل نطاق القطاع الكامل في تصميم القطاعات الكاملة العشوائية. هذه الزيادة قد تنتج خاصة إذا كانت المساحة التجريبية تنبئ بإحتمالية وجود تباينات داخلها نتيجة المعاملات الزراعية المختلفة التي تجري للمحاصيل المختلفة أو/ و طريقة تصميم شبكة الري السطحي بها. حيث تؤدي الأخيرة إلي زيادة مساحة الإستقطاعات البينية بين القطع التجريبية داخل القطاع الواحد. في كلتا الحالتين، لا يستطيع الباحث، بأي حال من الأحوال، أن يتحكم هكذا في وضع القطاع الكامل بقدر الإمكان متناسباً مع إتجاهات الإختلافات البينية الموجودة في التربة.

كان الشكل العام للتجربة ٢×٢ نسبة إلي وضع مكررات التجربة الأربع – أي مكررتين متجاورتين في كل صف وكل عمود. في كل مكررة، تم وضع الثلاث قطاعات الغير كاملة المكونة لكل مكررة متجاورة طولياً، وكان طول القطاع الغير كامل عمودي علي الإتجاه الطبيعي للمراوي والبتون. نتج عن هذا وجود فواصل بينية عرضية بين القطع التجريبية داخل كل قطاع غير كامل. وطبقاً لقواعد تصميم التجارب، قد تؤدي هذه الإستقطاعات بين القطع التجريبية داخل القطاع الغير كامل إلي زيادة توقع إحتمال حدوث تغايرات أكثر داخل القطاع الواحد مما قد يؤدي إلي زيادة الأخطاء التجريبية.

وبالرغم من زيادة هذه الإحتمالية لزيادة الإختلافات البينية داخل القطاع الغير كامل، بينت قيم معامل التحديد المتعدد Coefficient of multiple determination (R^2) للتصميم التجريبي المستخدم أن تطبيق التصميم المدمج

الكامل كان ناجحاً لحد كبيرفي تفسير التباينات الموجودة في كثير من العوامل التابعة الخاضعة للدرس في هذه البحث. إضافة لهذا، فقد كانت مساهمة القطاعات الغير كاملة ، كمصدر من مصادر التباين، مؤثرة في تفسير جزء من الإختلافات في الصفات المدروسة. أما من حيث قياس دقة التصميم المدمج نسبة إلي التصميم القطاعات الكاملة العشوائية، فلم تتعد قيم الكفاءة النسبية حاجز ١٠٦% علي مستوي جميع الصفات المحصولية المدروسة وكان تصميم القطاعات الكاملة لصفات أكثر كفاءة من التصميم المدمج. وعلي الفور قد تؤول مباشرة هذه النتيجة بأن الإدماج، في هذه التجربة، لم يؤت ما كان يهدف إليه. ولكن، مرجعية هذه النتيجة قد تكون مبشرة جداً في دحض هذا الإستنتاج المتسرع حيث أن التخلص مستقبلياً من وضع القطاعات الغير كاملة بالشكل الذي تم هنا ووضعها موازية طولياً لوضع المراوي والممرات البينية يحتاج لمزيد من التجريب. كما أن طبيعة نمو محصول الكانولا يضفي مصدراً آخر من الإختلافات فيما بين القطع المختلفة داخل القطاع الواحد فيما يتعلق بطبيعة التفريع وغياب بعض النباتات مما يؤثر سلبياً علي الدقة خاصة إذا كانت مساحة القطعة التجريبية صغيرة نسبياً.

علي جانب آخرفيما يخص أهداف البحث، كانت الكثافة النباتية في وحدة المساحة والصنف المستخدم هما العاملان الأساسيان الذين أديا إلي زيادة محصول البذور مقارنة بالعامل الثالث وهو ميعاد الحصاد. وبرغم إستخدام كثافات نباتية منخفضة نسبياً مقارنة بالمعدلات المستخدمة في مصر، إلا أن محصول البذور الناتج كان مرضياً جداً. حيث أثر هذان العاملان علي محصول البذور بتأثيرهما علي قدرة النبات علي إنتاج عدد أكبر من القرون مقروناً بوزن أكبر للبذرة الواحدة. وهذا قد يؤدي بدوره إلي التأثير الإيجابي علي كمية الزيت المنتج من وحدة المساحة. أري، إذن ضرورة دراسة مدي أوسع فيما يخص الكثافة النباتية، و حيث أن ميعاد الحصاد لم يؤد دوراً كبيراً بما يتعلق بكمية البذور الناتجة لوحدة المساحة، فمن المحتمل إذن من تغيرفي هذا الإتجاه بتغير في مواعيد الزراعة.

موعد الحصاد لبعض كثافات أصناف الكانولا فى تصميم مدمج

رسالة علمية مقدمة من

محمد فاضل طلبة زينهم

بكالوريوس العلوم الزراعية (محاصيل) كلية الزراعة بمشتهر جامعة بنها ٢٠٠٦

للحصول على

درجة الماجستير فى العلوم الزراعية

محاصيل

وقد تمت مناقشة الرسالة والموافقة عليها

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٢٠١٣