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PREDICTING THE CROP CYCLE FOR SUBSAHARAN AFRICA: METHODS AND DEVICES

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ABSTRACT

The purpose of this study is to address drought risk to cowpea farmers by identifying possible mixed lots of seed that spread risk. The method employed was a Poisson regression model using multi-year data for flowering time for 160 cowpea accessions. Two possible pairs of varieties for mixed seed release were identified, 1393-1-2-3(-) paired with Cameroon 12-58 and Sasaque paired with Tvu-9557. This study provides a new tool that can be used to predict the crop cycle for the lines and environments in the data set, which were in Pobe and Kamboinse, Burkina Faso. Further studies should consider consumer preferences, yield, disease resistance, and seed type.

Key words: Statistical modeling, Poisson regression, Climate change, Cowpea, Seed Production

INTRODUCTION

Cowpea (*Vigna unguiculata)* is a warm-season legume typically farmed as a staple by small-holder families in sub-Saharan Africa. Cowpea is a self-pollinated diploid species (Hall 1997). Cowpea cultivation began about 4,000 years before present (Hancock 2012).Flowering time is an important trait for cowpea domestication and is often considered to be a part of domestication syndrome. The suite of traits could include, early flowering, self- pollination, non-shattering, and large seed size (Ladizinsky, 1998).

Cowpea is adapted to marginal environments and is more tolerant to abiotic stress than soybean (*Glycine max),* for example (University of Florida Extension, 2013). An aspect of cowpea reproduction that is essential to the problem is that heat is a confounding factor to flowering (Mutters, 1998). Floral abortion occurs at 34°C in susceptible genotypes. Therefore, lines that flower normally under heat and drought stress must be identified to produce food for Africa in the context of climate change.

Discussion of drought risk mitigation has maintained its relevance due to the expected effects of climate change (Hassan 2019). Drought can occur during cowpea cultivation at the early seedling stage, mid-season vegetative phase, or during the late-season pod filling stage. One way to help ensure a harvest would be to plant both early and late season varieties. If farmers can purchase a single bag of seed that has both early and late season plants, they can possibly escape a late or midseason drought.

One option to spread drought risk would be to stagger plantings of the same cultivar. However, this creates more work for farmers and requires more resources. Additionally, the seeds could be delivered as near-isogenic lines. The NILs could be made by introgression of an early flowering segment of the chromosome into a late flowering line. After a few rounds of backcrossing, both of the NILs could be sold together in the same bag as a single cultivar.

However, since UC Riverside has the third-largest germplasm collection in the world with over 5,500 accessions, it is possible that there are compatible pairs of seed types in existence. The lines could be readily increased by self-pollination. That would allow quicker delivery of the seeds to farmers than going through the marker-assisted breeding cycle.

One of the most important traits for adapting to climate change is drought tolerance. Drought tolerance is linked to early flowering time (Muchero, 2013). Cowpea is attacked by the opportunistic plant fungal pathogen *Macrophomina phaseolina* under drought conditions.

Macrophomina resistance is linked to late flowering time (Muchero, 2011). Given this, it would be difficult to pyramid traits for drought tolerance and *Macrophomina* using traditional breeding methods and current sources of resistance. However, it may be possible to circumvent the necessity to breed both of these resistances into a single cultivar if a late and early variety could be marketed together in the same seed lot.

Although there is an intuitive aspect of farming the land, farmers will want to know what to expect from their purchased seed varieties. It is important to use statistical inference to aid farmers to make crop decisions. Planting these lines does not produce the same mean value for days to flowering in any given season. Mathematical models can be used to predict the mean values for days to flowering.

The study aims to address the risk of drought to smallholder cowpea farmers by considering mixed lots of seeds that spread risk, and also to identify late and early flowering cultivars while predicting flowering time. It will also create a framework for obtaining the probability of a cowpea accession flowering at the mean flowering time.

MATERIALS AND METHODS

Data Collection

50% flowering time is defined as a count of the number of days until 50% of the plants in the plot have open flowers. Data for 50% flowering time was collected in Burkina Faso from 2008-2009 in two locations.

Table 1: Summary of climatic conditions for cowpea field experiments conducted in Burkina Faso (Muchero, 2013)

Experiment	Months	Max Air Temp °C	Min Air Temp °C	ETO
BF_2008	Aug, Sept, Oct	32.1, 33.1, 36.8	22.8, 23.0, 22.5	40.0, 50.0, 58.1
BF_2009A&B	Aug, Sept, Oct	31.8, 35.0, 35.1	24.2, 23.5, 28.1	58.1, 58.0, 76.1
BF_2009C	Aug, Sept, Oct	31.1, 33.6, 37.0	22.5, 23.0, 24.2	62.0, 50.0, 59.3

It is notable that the maximum highest evapotranspiration values tended to be in the Pobe environments, which are hereafter referred to as Environments 2 and 3.

As shown in Table 1, environment 1 is BF_2008 from Kamboinse, environments 2 and 3 are BF_2009A&B in Pobe, and environment 4 is BF_2009C from Kamboinse, Burkina Faso. Using the model is dependent on knowing the climatic conditions of the area.

Cowpea was grown in a completely randomized design with three replications in each environment. The average flowering time values for all replications in each environment were used as the flowering time values for each accession and environment in the model. Data from 160 cowpea accessions was used for the analysis.

Model Selection

Statistical analysis was carried out in R. The first model that was considered for this analysis was the two-way analysis of variance (ANOVA). The proposed model was

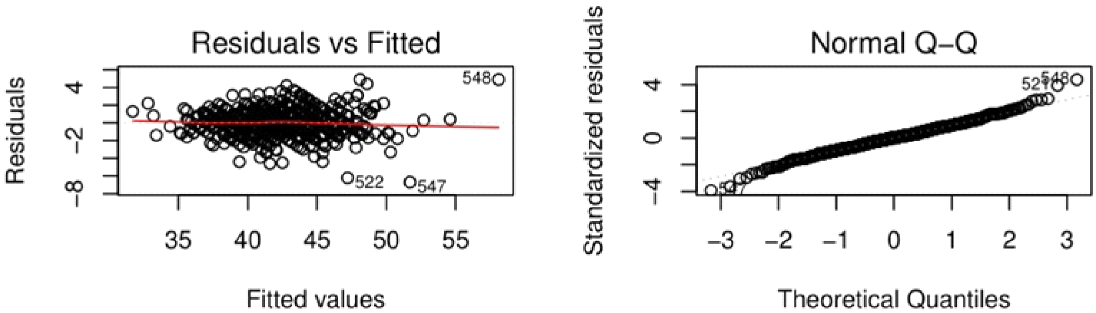

Figure 1. The res*fitted plot for cowpea flowering time shows a megaphone shape and the QQ plot suggests that the data may be non normal.

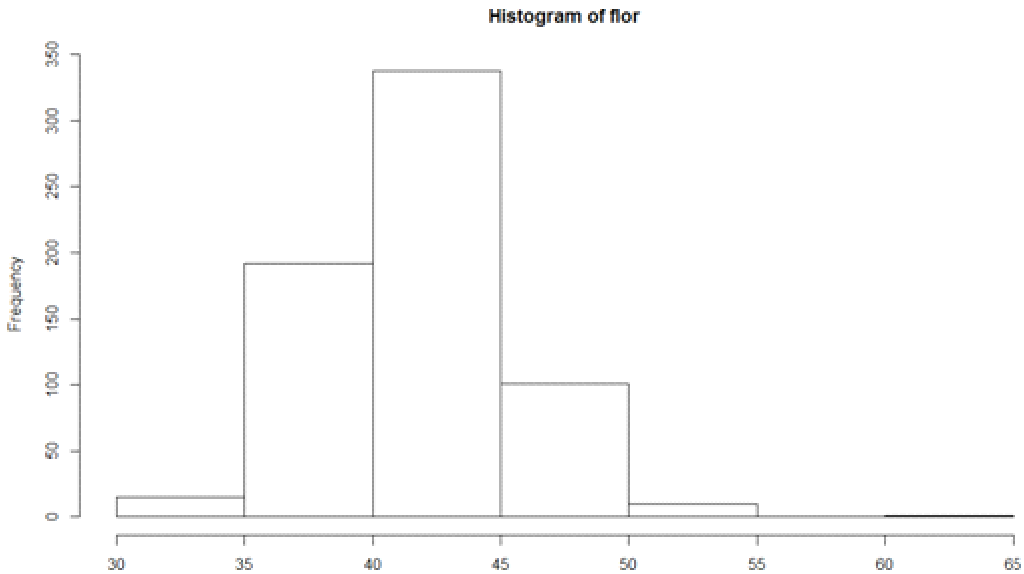

Figure 2: The histogram of cowpea flowering time data allows us to visualize the distribution of cowpea flowering time and provides evidence of non-normality.

Note the skewed distribution, where the highest frequency of 50% flowering time was between 40-45 days.

In addition to the non normality evidence shown in Figures 1 and 2, the Jarque-Bera test for normality was taken into account for model design and the output is shown below.

Table 2: Results of Jarque-Bera Normality Test for cowpea flowering time data

Test Statistic	P VALUE
Chi square	*Asymptotic p value*
65.6155	5.66E-15

Note the highly significant p-value which indicated that the normality assumption of the proposed linear model has been violated.

Jarque-Bera's test provided strong evidence of non normality (p=5.7x10^-15) and it was clear that another model would have to be considered (see Table 2 and Figure 2).

In light of these preliminary findings, a two-factor Poisson regression model was considered. The Poisson model is a good candidate when working with count data such as flowering time (Fávero, 2019). The model to be tested is

$$\text{In}\,(\mu i) = \mu + \beta + T$$

where μ is the global mean and variance, β is the effect of the environment, and the effect of T is the effect of the cowpea accession grown.

RESULTS AND DISCUSSION

Using Table 3, we can identify some potential pairs of lines that could be combined into a cultivar release with a ratio of x/y days to 50% flowering. A potential pair could be 1393-1-2-3(-) with Cameroon 12-58. The ratio for 1393-1-2-3(-) and Cameroon 12-58 is 0.72. Another potential pair is Sasaque with Tvu-9557. The ratio for Sasaque and Tvu-9557 is 0.71. A third match is Sasaque with Cameroon12-58. The ratio for Sasaque with Cameroon12-58 is 0.66.

Table 3: Predicted and observed values for the cowpea days to 50% flowering trait generated by Poisson regression

Accession	Predicted Days to 50% Flower	Observed Days to 50% Flower	Difference	Significant p-value
1393-1-2-3(-)	37 days	39 days	2	yes
Cameroon 12-58	52 days	49 days	3	yes
CRSPNiebe	47 days	46 days	1	yes
Sasaque	34 days	34 days	0	no
Tvu-9557	49 days	51 days	2	no
Montiero	48 days	46 days	2	yes
Tvu-16594	47 days	47 days	0	yes
UCR2567	49 days	49 days	0	yes

The Poisson model has been used as a quantitative tool in risk evaluation for credit decisions, for example (Rongda, 2014). In this study, a lower ratio means that there is a larger spread of the days to flowering. That could translate to a better spread of the drought risk for farmers. However, the predictors did not have a significant p-value for Sasaque or Tvu-9557. This reduces the confidence level in the estimations for these lines. Nevertheless, it is worth investigating if these seed types could be compatible with consumer preferences. Increasing confidence in these predictions requires the evaluation of the overall fitness of the model.

An unexpected result shown in Table 4 is that accession is not a significant factor, whereas some lines are known to be early or late, such as Early Scarlet. Environment is almost significant (p<0.01), which suggests that the model can be improved.

Table 4: Evaluation of the Poisson regression model for cowpea days to 50% flowering with environment and accession included as factors

Analysis of Deviance Table	LR Chisq	Df	Pr(>Chisq)
acc	138.647	163	0.91699
environ	3.167	1	0.07515

There is no significant evidence of interaction for accession and environment according to Table 5. However, some of the lines had significant genotype by environment interactions (see supplemental materials). These included both of the late flowering accessions, Cameroon12-58 and Tvu-9557. The model was run taking only environment into consideration to analyze the result of excluding the accession effects.

Table 5: Test for interaction in the cowpea 50% flowering time Poisson regression model

Analysis of Deviance Table	Model	Resid. Df	Residual Deviance	Df	Deviance
acc	1	492	60.77		
acc+environ	2	491	57.603	1	3.168

Ultimately, the interaction term was omitted from the model based on the weak evidence for interaction.

Indeed, with the model

In $(\mu i) = \mu + \beta$

there is a highly significant effect for environment, as seen in Table 6. Therefore the model is improved by dropping the variable accession. In addition, this model allows us to perform Tukey's test since we had a positive Chi square result for environment ($p<0.0005$). The results of Tukey's test are shown in Table 7.

Table 6: Evaluation of the Poisson regression model for cowpea 50% days to flowering with the accession variable dropped

Analysis of Deviance Table	LR Chisq	Df	Pr(>Chisq)
environ	17.768	3	0.0004912***

It is clear from this evidence that environment is the most important factor in determining cowpea flowering time.

The results of Tukey's test show that the growing conditions in environment 3 and 2 were significantly different in terms of their effect on days to 50% flowering ($p<0.003$). In addition, the p-value of 0.006 for the comparison of environment 4 to environment 2 is an indication that the conditions were significantly different.

Table 7: Results of Turkey's multiple comparison test for the environments where cowpea was grown

Linear Hypotheses	Estimate	Std. Error	z-value	Pr(>|z|)
2 - 1 == 0	-0.40854	0.39326	-1.039	0.72658
3 - 1 ==0	0.97561	0.39326	2.481	0.6305 .
4 - 1 ==0	0.88415	0.39326	2.248	0.11026
3 - 2 ==0	1.38415	0.39326	3.52	0.00262**
4 - 2 ==0	1.29268	0.39326	3.287	0.00564**
4 - 3 ==0	-0.09146	0.39326	-0.233	0.99557

It is worth noting that Environments 2 and 3, which were both Pobe locations, were significantly different from one another in terms of 50% flowering time for cowpea. Environment 2 draws the attention; this location tended to have slightly lower flowering times.

Next, it is useful to look at our four chosen accessions in more detail. It is important to evaluate if there is a big difference in predicted values across environments. For this analysis, we are forced to rely on the first model which had accession included in order to make the prediction. The result of the analysis is shown in Table 8.

Table 8: Predicted days to 50% flowering detailed by environment for the four candidate accessions for variety release

Accession	Environment	Predicted 50% flowering
1393-1-2-3(-)	Environment 2	37 days
1393-1-2-3(-)	Environment 3	38 days
1393-1-2-3(-)	Environment 4	38 days
Cameroon 12-58	Environment 2	52 days
Cameroon 12-58	Environment 3	52 days
Cameroon 12-58	Environment 4	53 days
Sasaque	Environment 2	34 days
Sasaque	Environment 3	34 days
Sasaque	Environment 4	35 days
Tvu-9557	Environment 2	48 days
Tvu-9558	Environment 3	49 days
Tvu-9559	Environment 4	49 days

Note that Sasaque has the shortest predicted flowering time overall, and Cameroon 12-58 has the longest predicted flowering time overall.

According to Table 8, there is not an obvious difference in the number of days to 50% flowering across environments. However, there is a general trend that in environment 4 the plants take longer to flower. This also can give farmers the understanding that they may experience a small difference in the flowering time we predict versus the days to flower in their field.

CONCLUSION

Two possible pairs of varieties for mixed seed release were identified, 1393-1-2-3(-) paired with Cameroon 12-58 and Sasaque paired with Tvu-9557. To further determine whether the traits for these accessions will conform to consumer preferences, it will be necessary to look at yield, disease resistance, and seed type. A possible improvement to the study would be to group the accessions into early and late binomial categories to analyze the effects for the accession grown. It would also be helpful to augment the data with more environments in order to expand the applicability of the predictions. However, this study provides a new tool that we can use to predict the crop cycle for the lines and environments in the data set.

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Conflict of Interest Statement

The author declares that there is no conflict of interest regarding the publication of this paper.

Data Availability Statement

Cowpea Flowering time data is available by request.

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