REVIEW ARTICLE Agricultural Reviews, Volume 41 Issue 1: 79-84 (March 2020)

Breeding for Yield, Quality and Associated Traits in the Zimbabwean Flue-Cured Tobacco (*Nicotiana tabacum* L.): A Review

Justify Gotami Shava[1], Susan Richardson-Kageler[2], Shorai Dari[2], Frank Magama[1], Dzingai Rukuni[1]

10.18805/ag.R-122

ABSTRACT

Tobacco (*Nicotiana tabacum* L.) has grown to become a major cash crop and foreign currency earner in Zimbabwe. The crop's popularity in the country is dependent on the climatic and soil conditions that promote the production of flavour style cures which are well sought after by the majority of tobacco merchants and cigarette manufacturers across the world. The success story of tobacco farming in Zimbabwe is mainly attributed to the presence of an organised research system in the form of the Tobacco Research Board (TRB) that includes a dedicated division in the research unit specialising in variety development and promotion. Improvement in yield and quality of the cured leaf has are the main objectives of flue-cured tobacco breeders. Since the beginning of research in flue cured tobacco production in Zimbabwe, a lot of effort has been dedicated to improving these and other associated traits. This review paper traces the process of breeding for improvement in yield and quality in flue-cured tobacco in Zimbabwe. It shows the methods employed and identifies some of the potential sources of genes for use in improvement in flue-cured tobacco yield and quality in present and future breeding work.

Key words: Flue-cured tobacco, *Nicotiana tabacum* L., Tobacco breeding, Variety improvement.

The discovery that Zimbabwe could be a good flue-cured tobacco producing country that could rival America was predicted as early as 1892 (Mbanga, 1991). Tobacco varieties grown earlier in Zimbabwe prior to the 1890s were of the genus *Nicotiana rustica* L. widely thought to have been introduced by the early Portuguese traders since tobacco is not native to Africa. This type of tobacco was found to be pungent and harsh to the early white settler smokers and never considered for large scale commercial production. There were no flue-cured tobacco types in the country available for commercial cultivation. At the time, the world tobacco industry, focused on pipe tobacco which was heavy for most smokers (Mbanga, 1991). It took the early tobacco farm leaders to predict that the light tobaccos were going to be the dominantly smoked tobaccos in the world and started the import of flue-cured tobacco varieties from the USA for cultivation in Zimbabwe (Tanser, 1991).

The formal cultivation of improved flue-cured tobacco (*N. tabacum* L.) varieties in Zimbabwe began during the 1894-1895 (Tobacco Research Board, 1999). Before the development of locally adapted flue-cured tobacco varieties, early tobacco farming relied mainly on introduced variety mainly from the USA and Canada (Mbanga, 1991).

A farmer by the name of South is credited with first introducing flue-cured tobacco varieties in Zimbabwe and the cultivation of the crop (Mbanga, 1991). As early as 1903, South had imported seven varieties and sowed them on a farm west of Harare, including the varieties 'Hester', 'Goldfinger' and 'Ragland's Conqueror' from the USA.

[1]Tobacco Research Board, Airport Ring Road, P O Box 1909, Harare, Zimbabwe.

[2]Crop Science Department, University of Zimbabwe, P O Box MP 167, Mt Pleasant, Harare, Zimbabwe.

Corresponding Author: Justify Gotami Shava, Tobacco Research Board, Airport Ring Road, P O Box 1909, Harare, Zimbabwe. Email: gotamigav@yahoo.com

How to cite this article: Shava, J.G., Richardson-Kageler, S., Dari, S., Magama, F. and Rukuni, D. (2020). Breeding for Yield, Quality and Associated Traits in the Zimbabwean Flue-Cured Tobacco (*Nicotiana tabacum* L.): A Review. Agricultural Reviews. 41(1): 79-84.

Submitted: 07-03-2019 **Accepted:** 11-01-2020 **Published:** 24-03-2020

Through the selection efforts of South, varieties like 'Bonanza', a descendent of the introduced variety 'Goldfinger', became the foundation of early tobacco production in Zimbabwe. They were sold as South's Seed. The main quality objective of variety development during these early years was the development of a lighter (yellow) leaf that would replace the heavy tobaccos popular during those early days (Mbanga, 1991). Later on, varieties like 'Hickory Prior' became very popular. Thus, the early varieties to be grown in Zimbabwe were mainly introductions from which locally adapted pure line varieties like 'Bonanza' were selected for eventual cultivation.

Formal exotic variety evaluations started in 1910 and continued up to 1924 under the guidance of the then Department of Agriculture but the work focused mainly on fertiliser and insect studies (Mbanga, 1991). Prior to this,

interested farmers would individually import seeds of varieties and cultivate them on their farms without any testing (Shava *et al*., 2019). The first general research station with tobacco as mandate work opened in 1924 (Tobacco Research Board, 1996). However, it was not until 1934 that a research station dedicated to tobacco research was opened in Trelawney that tobacco breeding work targeted at developing locally adapted, high yielding cultivars with accepted quality was initiated. (Tobacco Research Board, 1998; Tanser, 1991; Mbanga, 1991).

Breeding for yield in flue-cured tobacco

The first crosses aimed at improving yield in flue-cured tobacco in Zimbabwe were done during the 1952-53 season (Gildenhuys, 1953). The yield improvement crosses involved introductions which included 'Meadows Giant', 'Virginia Gold', 'Delcrest' and 'Bonanza'. Gildenhuys (1953) studied heterosis for yield in flue-cured tobacco and determined that yield was always intermediate between the respective parents forming the hybrids but not statistically significant. Gami and Chauhan (2013) also reported the same trend working on beans. During the same studies, it was also found that yield would at times approach the superior parent but did not surpass it (Gildenhuys, 1952). These early studies confirmed that the varieties 'Meadows Giant' and 'Virginia Gold' were the highest yielders at the time.

Further work on breeding for yield improvement in flue cured tobacco was later aimed at having varieties with the yield of 'Virginia Gold 136', a selection made in Zimbabwe from the American introduction originally known as 'Virginia Gold' and the quality of 'Delcrest'.

A parallel program to improve the early introduced varieties, 'Hicks' and 'White Stem Orinoco', for local adaptation was started in 1952. These selections were evaluated together with other locally developed selections from early variety introductions. The selections were constantly evaluated against the commercially acceptable varieties and recently released introductions from other countries at the time.

Early flue-cured tobacco breeding for yield improvement relied on the initial crosses done for other objectives like disease resistance. As selection for disease resistance and acceptability for cultivation took place, so did selections for yield and yield related parameters such as high leaf number and large leaf size. Later on, mammoth mutations which have high leaf potential emerged from some of the early selected varieties and these attracted the attention of breeders wanting to improve on the yield potential of the early varieties. During the 1963-64 season a mutation selection from the recently released variety 'K51' was tested for the first time under the name 'Mammoth Kutsaga 51' (Raeber and Schweppenhauser, 1964).

During the same period, optimum topping height for achieving the highest yield potential of varieties and lines were conducted. Research indicated that a topping height of 18 to 20 leaves was the best for local varieties. The varieties 'Kutsaga E1' (K E1) (Fig 1a) and 'Kutsaga E2' (K E2) compared favourably with other early popular varieties like 'Hicks' and 'Kutsaga 51' for both yield and quality. However, any stress from cold, drought, excessively wet, or poor agronomic practices promoted early flowering, a lack of upper leaf expansion and leaf texture in the upper leaves of these varieties (Raeber and Schweppenhauser, 1964). These varieties were improved for these weaknesses through the cross ('K E1' × 'Kutsaga Mammoth') × ('K E2' × 'Kutsaga Mammoth') and selfing for five generations to resemble K51 (Raeber and Smeeton, 1973d).

Trials in the 1960s showed that the variety 'Kutsaga Mammoth' could yield 500 kg more than the standard non-mammoth varieties (Raeber and Smeeton, 1973d). As a result, this variety was introduced as a prescribed variety during the 1968-69 season. However, it never gained popularity because it was susceptible to white mould and difficult to cure because it is easily turned "black" in the barn guinea fowl spot easily occurred. A programme to breed for white mould resistance into the variety was started during the 1966-67 season which resulted in a line coded 18-2 and was later named 'Kutsaga Mammoth E1' (K ME1) and replaced 'Kutsaga Mammoth' (Raeber and Schweppenhauser, 1967). During the 1980s the variety 'Kutsaga Mammoth 10 which has resistance to wildfire, white mould and TMV and a selection from the cross WMRM81N-1 × TWM296-2a was released. WMRM81N-1 is a white mould resistant mammoth line and TWM296-2a is a wildfire and TMV resistant



(a) K E1 (b) T 72

Fig 1: Appearance of one of the early varieties KE1 developed in the 1960s and the modern variety T72 developed in 2015.

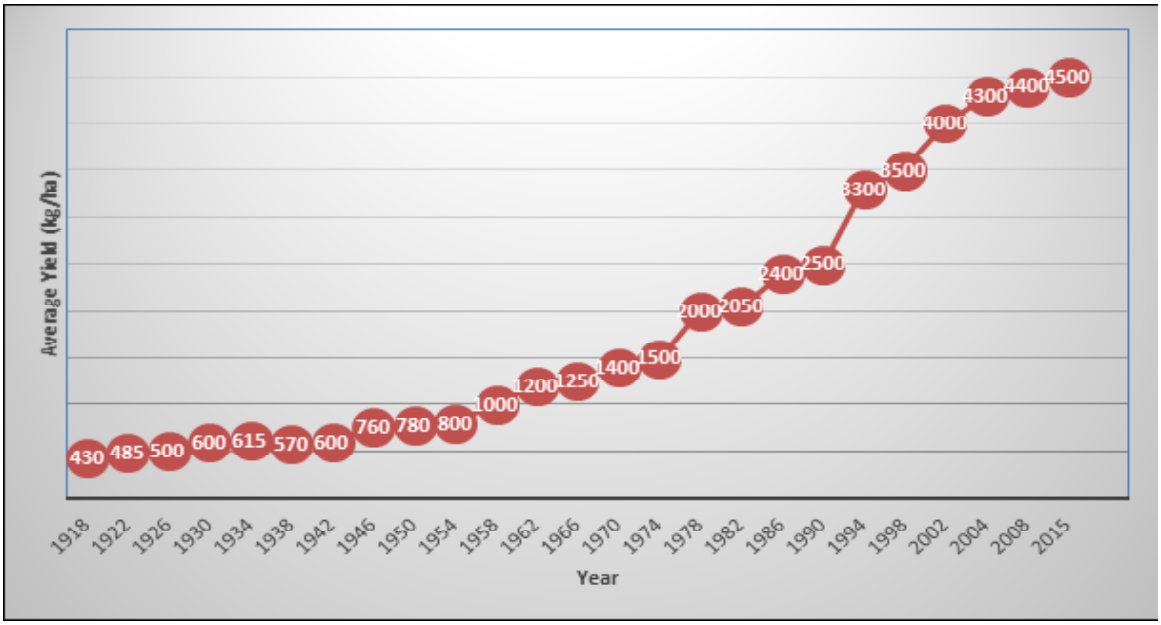


Fig 2: Changes in average flue-cured yield performance from 1918-2015.

mammoth line (Raeber and Smeeton, 1984). During the 1983-84 season, notable entries in the yield and acceptability trials were S_8AW22-10-1-1-3R with white mould, wildfire, Alternaria leaf spot and Tobacco Mosaic Virus resistance as well as S_8AW22-10-1-1-6S and S_5STNCA1-56-52-34. It took until the late 1980s and early 1990s for the fruits of the early breeding efforts for yield improvement to be enjoyed when elite lines from many breeding efforts were constituted into high yielding varieties availed to farmers for field production (Fig 2).

Dihaploid breeding of flue-cured tobacco in Zimbabwe

During the 1960s, dihaploid breeding gained popularity in the world as a potential method to quicken the breeding cycles in many crops. This method was also adopted in Zimbabwe for breeding flue-cured tobacco (Raeber and Smeeton, 1976b). The first batch of dihaploid lines developed through anther culture were coded DETW lines from the F_1 of TW441-1C or 440-1b × 'K51E' and had white mould, wildfire and TMV resistance (Raeber and Smeeton, 1976d). However, although the method produced viable lines, studies at Kutsaga Research Station in Zimbabwe showed that nicotine, sugar and total N concentrations varied widely between dihaploids and their parents (Raeber and Smeeton, 1976d). It was determined that those dihaploids with high yields also had low nicotine and high sugar concentrations. Only the line D110 from the DETW lines proved to be promising and had wildfire, TMV and white mould resistance. This line was later named 'K110' (V617) and registered in 1977. It was reported by Burk and Matzinger (1976) that the dihaploid breeding method was a less valuable breeding technique than originally thought and the dihaploid programme was shelved.

The use of male sterility in tobacco breeding in Zimbabwe

Male sterility is a condition in where plants are unable to produce or release viable or functional pollen grains because of either failure of formation or an abnormality in the development of pollen grains, stamens or gametes. Male sterility was first discovered in tobacco in the USA (Clayton, 1950). It was later reported that the condition occurs spontaneously in many species of tobacco especially the wild species. Work on introduction of male sterility in tobacco in Zimbabwe started in the early 1960s. However, the male sterile lines were first tested during the 1978-79 season when it was found that male sterile lines behaved like normal lines (Raeber and Smeeton, 1979a). Since that time effort was made to develop male sterile lines to use in hybrids for purposes of seed security and maintenance of variety stability. Today in Zimbabwe it is now standard practice for all tobacco varieties put on the market to possess male sterility.

The use of hybrids in tobacco farming

Studies in Zimbabwe conducted during the early 1950s reported that there was no heterosis for yield in flue-cured tobacco among the lines evaluated (Gildenhuys, 1952). Heterosis was, however, found for quality. Therefore, subsequent work focused on developing pure line varieties instead of hybrids. The first attempt to develop hybrids in flue cured tobacco was in 1979 when the first batch of fertile hybrids was evaluated in a multi-location trial. It is believed that this attempt was driven by the desire to combine resistance to multiple diseases in one variety as well as consolidating quality. The first hybrids to be made involved 'K 51' and ETW lines which have resistance to white mould, wildfire race 0 and TMV (Raeber and Smeeton, 1979b).

Other crosses made were between AE and 'K110' to give a hybrid with resistance to four diseases, Alternaria leaf spot, white mould resistance, wildfire resistance and TMV resistance. The first hybrid tobacco seed with male sterility to be put on limited release for cultivation by growers was constituted from the cross m/s 'K E1' × 'Speight G28'.

Breeding for ripening rate in tobacco

Early work on breeding for ripening rate in flue-cured tobacco aimed at developing a fast ripening white mould resistant cultivar. This character was derived from the Argentinian variety 'INTA-Carrillos 69' which was crossed to 'K E1' and the F1 in turn crossed to the white mould resistant line WNR19-100-2e (Raeber and Smeeton, 1974). The study showed that fast ripening character in 'INTA-Carrillos 69 was controlled by a single dominant gene. It was later discovered that the pale yellow breeding line PY 10 (V599) bred by Dr J F Chaplin (USDA) came from the line designated TI 1372 from Argentina (Raeber and Smeeton, 1974). In TI 1372 it was also discovered by Dr Chaplin that the character was controlled by a single dominant gene. From the breeding work at Kutsaga Research Station in Zimbabwe, only the line PY-T-19-1 was retained and entered in the institution's accession register as V643. This line has a dominant controlled fast ripening character (Raeber and Smeeton, 1977).

Breeding for reduced suckering

During the 1998-99 season, a rogue 'K M10' plant was found to possess reduced suckering behaviour. Evaluations were done on the line which showed that heritability for reduced suckering was high enough for selection to be effective.

Breeding for cured leaf quality

Quality is defined as suitability for intended purpose and is determined mostly by the use to which a product will be put. Quality in tobacco refers to three aspects namely, chemical composition, smoke properties and leaf handling or appearance properties. Unlike in other qualitative traits like flower colour in chickpeas (Halan and Deb, 2013), inheritance of most quality traits in flue-cured tobacco is not monogenic but polygenic. Parameters have been designed to assess these quality traits so that they fall within acceptable limits for all the varieties developed. In every breeding programme, these quality aspects of tobacco are always assessed and outliers discarded in favour of the lines falling within acceptable boundaries. Cured leaf style (Fig 3) was one of the traits selected for during the breeding processes. Studies conducted by Gildenhuys (1952) reported the presence of heterosis for cured leaf style in flue-cured tobacco with crosses giving better cured leaf styles than their respective parents. The same studies also revealed that variety Bonanza was the leading quality variety available among all the introductions and locally developed selections at that time. This section of the review, however tackles mostly smoke and chemical properties selection processes carried out by early tobacco breeders in Zimbabwe to addresses these quality aspects in flue cured tobacco.

Breeding for sugar and nicotine content

Most of the early breeding lines and varieties to be grown in Zimbabwe were elite introductions from the USA with already well defined compositions. These needed no further improvement in this aspect. Deliberate breeding for high nicotine content in flue-cured tobacco started in the mammoth lines after realising that these lines had relatively low levels of the alkaloid (Raeber and Smeeton, 1976a). Studies on nicotine content began with crosses between 'K51E' and 'Florida 22', A124N, A22N, WFM29 and NR89 in a diallel cross. Other experiments aimed at screening available varieties for nicotine levels were also conducted and they proved that line 'TI 501' (V588) had the highest nicotine content among the available varieties of 3.68% of total dry mass (Raeber and Smeeton, 1976c).

Breeding for smoking quality

After the discovery that the locally available tobacco types had harsh smoke properties in the late 1890s, a decision to import varieties for the establishment of the local industry was made (Mbanga, 1991). Since then, no effort was made to improve the smoke properties of these early introductions as they were improved varieties with acceptable smoking quality and already in cultivation in their countries of origin (Mbanga, 1991). The problems of unacceptable smoke characteristics came later when the breeders sought to improve elite varieties using other types of tobacco like cigars or wild species. One instance was the discovery that flue-cured breeding lines with Alternaria resistance derived from the South American cigar variety 'Beinhart 1000-1' had their Alternaria resistance gene closely linked to cigar aroma (Raeber and Smeeton, 1975). Breeding programmes had to be employed to break this linkage and lines like AE48-18 emerged with good Alternaria resistance and good aroma.

Smoke evaluations on flue-cured tobacco were first reported during the 1970-71 season involving the varieties



a. Orange style tobacco b. Lemon style tobacco

Fig 3: Orange ("dark") and lemon ("light") cured style tobacco.



Fig 4: Assessing and scoring for smoking quality in flue-cured tobacco samples.

'SCR' and 'Kutsaga 51B'. The parameters assessed were smoke strength, throat catch, palate sensation, smoke taste, overall impression, burning quality and the colors of ash produced (Raeber and Smeeton, 1971a) (Fig 4). Assessment samples were taken from tobacco grown in the fast, medium and slow growing areas of tobacco in Zimbabwe. The lower and upper leaf positions of the plant were the only parts evaluated during these early days unlike now where the middle portions are also included (Raeber and Smeeton, 1971b). Other field trials, however, found that the variety 'Kutsaga 51B' was susceptible to wind breakage and white mould. It was also found to be difficult in tying the reaped leaf and producing a pleasant cure, hence, the variety never gained popularity though it passed the smoke evaluations (Raeber and Smeeton, 1971c).

Breeding for drought resistance in flue-cured tobacco

Tobacco has a fibrous root system with a pronounced tap root in many cultivars. Since it is a bushy herbaceous perennial plant grown as an annual, tobacco is regarded as a drought resilient crop. As a result, breeding for drought tolerance in tobacco was not aimed at mere survival of the crop under drought conditions but rather, to compare varieties with respect to their tendency to scorch and ability to recover from the shock of drought when conditions become favourable. On early screening for sun-scorch among varieties, it was shown that lines M7, 151 and 'Virginia Gold' were more resistant to the problem (Raeber and Schweppenhauser, 1965).

Later on, it was found that varieties 'K110' scorched highest, 'K ME' and 'K110' flowered early and that 'K E1' does not easily recover from drought and that its leaf area expansion is retarded fast (Raeber and Smeeton, 1978). This makes it very easy to get green grades with 'K E1' and related varieties.

CONCLUSION

Organised breeding work for flue-cured tobacco improvement in Zimbabwe started during the first half of the

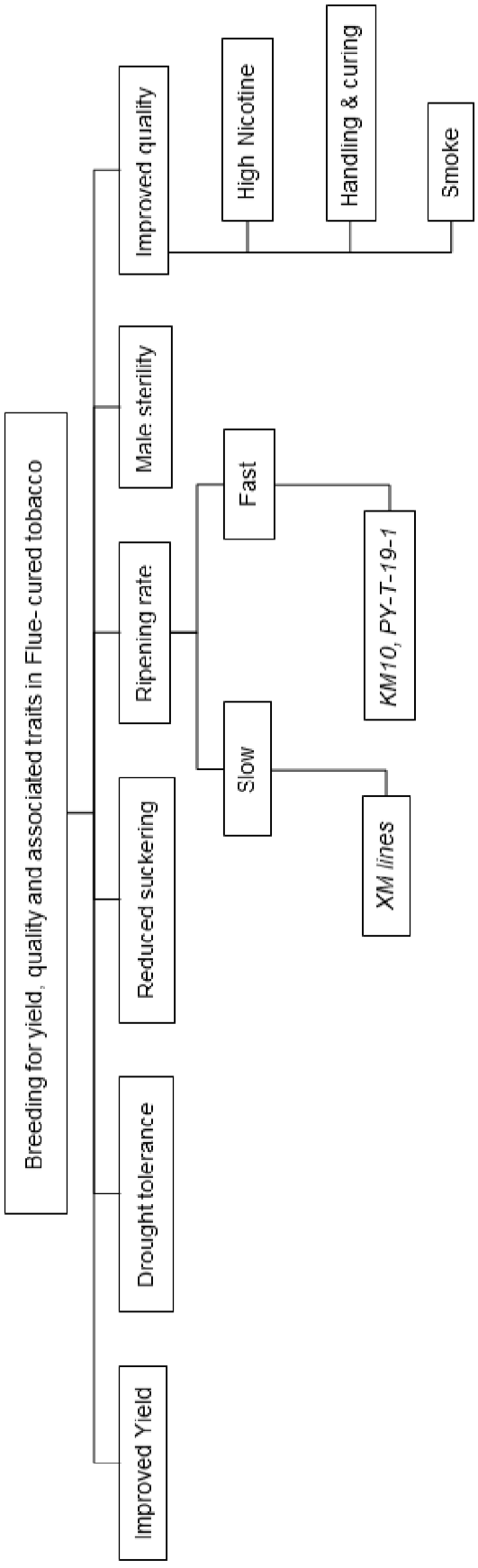


Fig 5: The main objectives of flue-cured (*Nicotiana tabacum* L.) breeding in Zimbabwe and the potential sources of major traits in the modern flue-cured tobacco germplasm.

20th Century after the establishment of the Trelawney Research Station in Mashonaland West Province. The first 20 years of the breeding effort sought to address the majority of the flue-cured tobacco variety limitations in the country. Flue-cured tobacco breeding in Zimbabwe used approaches like variety introductions, interspecific hybridization, recurrent selection, bulk selection, backcross breeding, double haploid breeding and pedigree breeding to produce the advanced germplasm available in the country. Linkages to undesirable traits found in wild species of tobacco delayed the production of acceptable lines whenever other species of tobacco other than *N. tabacum* were used as sources of valuable traits. However, most of the products of the 60 years of breeding effort are yet to be exploited in the development of superior varieties for farmers. There is, therefore, potential in the present germplasm in Zimbabwe to solve the current challenges faced by growers in the country including threats from diseases, shifts in quality preferences and improvements in yield.

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