

Pod Ontogeny in Cowpea
[*Vigna unguiculata* (L.) Walp]

**A
THESIS
SUBMITTED TO THE
MAHATMA PHULE KRISHI VIDYAPEETH
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE AWARD OF THE DEGREE**

OF

DOCTOR OF PHILOSOPHY (AGRICULTURE)

IN

**AGRILCULTURAL BOTANY
(PLANT PHYSIOLOGY)**

By

Deshmukh Devidas Vishnu

(Regn. No. 08/19)

**DEPARTMENT OF AGRICULTURAL BOTANY
POST GRADUATE INSTITUTE
MAHATMA PHULE KRISHI VIDYAPEETH
RAHURI-413 722, DIST.: AHMEDNAGAR
MAHARASHTRA, INDIA
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In partial fulfillment of the requirements for the degree
of
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in

AGRICULTURAL BOTANY
(PLANT PHYSIOLOGY)

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2011

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The assistance and help received during the course of this investigation have been acknowledged.

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C E R T I F I C A T E

This is to certify that the thesis entitled, "**POD ONTOGENY IN COWPEA [*Vigna unguiculata* (L.) Walp]**", submitted to the Faculty of Agriculture, Mahatma Phule Krishi Vidyapeeth, Rahuri, Dist.: Ahmednagar, M. S. for the award of the degree of **DOCTOR OF PHILOSOPHY (AGRICULTURE)** in **AGRICULTURAL BOTANY (PLANT PHYSIOLOGY)**, embodies the results of a bona fide research work carried out by **MR. DEVIDAS VISHNU DESHMUKH**, under the guidance and supervision of **DR. S. N. MATE**, Professor, Department of Agricultural Botany MPKV, Rahuri and that no part of this thesis has been submitted for any other degree or diploma.

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ABBREVIATIONS AND LOCAL TERMS

@: at the rate of	LAR: Leaf area ratio
ADP: Adenine diphosphate	LWR: Leaf weight ratio
AGR: absolute growth rate	MPL: mid-pericarp layer
APDP: Actual pod development periods	N: Nitrogen
ASGP: Actual seed growth periods	NADP: Nicotinamide adenine diphosphate
ATP: Adenine triphosphate	NAR: net assimilation rate
CER: carbon exchange rate	PDP: pod development period
CHICKGRO: Chickpea crop growth model	PEP: Phospho-enol pyruvate
CO ₂ : Carbon dioxide	PFD: Photosynthetic flux density
DAA: Days after anthesis	P _m / P _n : rate of photosynthesis
DAF: Days after flowering	PNUTGRO: Groundnut crop growth model
DAS: Days after sowing	PS: Photosystem
DW: dry weight	RD: Recommended dose
EFPD: effective filling period duration	RGR: relative growth rate
e.g.: for example	RLA: Leaf appearance rate
EPDP: Effective pod development periods	RUBISCO: Ribulose biphosphate corboxylase oxygenase
ESGP: Effective seed growth periods	RuBP: Ribulose biphosphate
<i>et al</i> : and others	RWR: root weight rate
ETR: electron transport rate	SC: stomatal conductance
FSSA: final stage of seed abortion	SCA: specific combining ability
FYM: Farm yard manure	SFP: seed filling period
GA ₂₀ : Gibberallic acid	SGR: Seed growth rate
GCA: general combining ability	SLA: Specific leaf area
HI: Harvest index	T _b : base temperature
IITA: International Institute of Tropical Agriculture	TDM: Total dry matter
LAD: Leaf area duration	TR: transpiration rate
LAI: Leaf area index	ULR: unit leaf rate
	WUE: Water use efficiency

ABSTRACT

“POD ONTOGENY IN COWPEA [*Vigna unguiculata* (L.) Walp]”

by

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A

candidate for the degree

of

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Research Guide	:	Dr. S.N. Mate
Department	:	Agricultural Botany

Ontogeny (*ontos* present participle of 'to be', *genesis* 'creation') describes the history of events of the development of an organism from the fertilized egg to its mature form. Legumes are plants that bear their seeds in pods. Reproductive growth in grain crops is initiated by flowering and a period of pod or seed set. In cowpea, the overall yield depends upon number of pods as well as number and size of seed. Therefore, the study was undertaken on “Pod Ontogeny in Cowpea [*Vigna unguiculata* (L.) Walp]” at Pulses Improvement Project, Mahatma Phule Krishi Vidyapeeth, Rahuri, Dist.: Ahmednagar during *Kharif* seasons of 2009 and 2010 by considering the following objectives;

Abstract contd ...
Mr. D. V. Deshmukh

1. To investigate various events from setting of floral bud till maturity of pods in context of various growth characters in cowpea varieties
2. To estimate pod and seed filling rates in context of length of pod and size of seeds in cowpea varieties
3. To investigate total, actual and effective filling periods and their relation with actual and effective filling rates in cowpea varieties
4. To assess growth rate and photosynthetic rate in cowpea and
5. Analysis of starch, carbohydrates and protein content during pod development in cowpea

Five genotypes of cowpea viz. VCM 8, Konkan Safed, Phule Pandhari, C 152 and GC 3 were sown in RBD with four replications. The gross and net plot sizes were 4.00 x 3.60 m² and 3.60 x 3.00 m² adopting 30 x 10 cm spacing. At 50 per cent flowering 500 flowers were tagged in each treatment. From the date of tagging, 10 flowers/ pods were sampled at an interval of 3 days in each genotype in every replication. The observations on fresh weight, dry weight, length, girth and volume etc of flowers, pods, pod shell and seeds were recorded. The effective pod and seed growth rate and lag periods were calculated by Daynard *et al* (1971) and Wien and Ackah (1978). Phenological data were recorded from appearance of flower bud to crop maturity as characters of reproductive growth. Randomly 5 plants were sampled at 20 days interval from each plot for dry matter and assimilate partitioning in component parts of plants, estimation of leaf area and growth

Abstract contd...
Mr. D. V. Deshmukh

analysis (Radford, 1967). The rate of photosynthesis (P_n), transpiration rate (E) and stomatal conductance (g_s) were measured using Infra-red Gas Analyzer. Post harvest observations were recorded on the characters related with generative growth and sink capacity. The biochemical parameters of seeds and chlorophyll content of pod wall were estimated at various stages of growth. Data were analyzed statistically for analysis of variance (Panse and Sukhatme, 1985) and polynomial regression analysis (Fisher and Yates, 1963).

The genotypes, C 152, Konkan Safed and Phule Pandhari had higher values for pod length, pod girth, pod diameter, seed length, seed diameter, fresh and dry weights of pod wall, seeds/pod and pods at various stages of growth. As per the polynomials fitted for above parameters, the early maturing genotypes, VCM 8 and GC 3 maintained lower b_0 and higher b_1 values revealed rapid increase in pod and seed during the course of growth from the extremely small value at 0 times i.e. at anthesis. The genotypes, VCM 8 and GC 3 had higher growth rate and relative growth rate of seeds and pods at initial stages of growth with ceases with advancing age of the crop growth.

The five genotypes were categorized into following three classes.

1. Short pod development period (PDP) and seed growth periods (SGP) with higher pod development period (PDR) and seed growth rate (SGR) viz. C 152 and VCM 8.

Abstract contd ...
Mr. D. V. Deshmukh

2. Medium pod development period (PDP) and seed growth periods (SGP) with constant pod development period (PDR) and seed growth rate (SGR) viz. Konkan Safed and GC 3.
3. Long pod development period (PDP) and seed growth periods (SGP) with slow pod development period (PDR) and seed growth rate (SGR) viz. Phule Pandhari.

The appearance of first flower bud in VCM 8 was 33.00 days, which was 41.00 days in other genotypes. The average duration of the appearance of first flower bud and flower was 42.10 and 43.05 days, respectively. The average duration for days to setting of first pod was 44.05 days. The average duration of first pod maturity was 62.60 days. The duration from appearance of first pod to first pod maturity was approximately 18 days. The last pod maturity occurred in 74.00 to 87.00 days with an exception of VCM 8 (69.00 days).

The genotype, Konkan Safed and C 152 had higher dry matter production and it's assimilation in component parts of plant at various stages of growth, high magnitude of growth parameters, rate of photosynthesis and transpiration. GC 3 and C 152 had higher water use efficiency and stomatal conductance.

Phule Pandhari and C 152 recorded more plant height and number of branches per plant, whereas, Konkan Safed recorded higher number of leaves, leaf area per plant and bold seed size. The genotypes, C 152 and Phule Pandhari were found to be promising

Abstract contd ...
Mr. D. V. Deshmukh

for yield and yield contributing characters. The genotypes, GC 3 and VCM 8 maintained higher harvest index.

The genotype, Konkan Safed was promising for the protein content followed by VCM 8 and Phule Pandhari. The higher chlorophyll 'a', 'b' content and total chlorophyll was maintained by the genotypes, VCM 8, Phule Pandhari and GC 3 at various stages of growth.

It is concluded that the genotypes, C 152, Konkan Safed and Phule Pandhari have higher pod and seed lengths, breadth, diameter, volume and weights. The actual and effective growth periods and lag periods were shorter in C 152 and VCM 8. VCM 8 and GC 3 possess higher seed and pod growth rates and relative growth of seeds and pods. VCM 8 and GC 3 begin reproductive growth at 12-15 days earlier than other genotypes. Higher dry matter production and its assimilation in component parts of plants, growth functions, physiological characteristics, vegetative growth and source characters and generative growth and sink capacity were maintained in genotypes C 152, Konkan Safed and Phule Pandhari. VCM 8 and GC 3 were promising for boosting up early characteristics in breeding programme, whereas, C 152, Konkan Safed and Phule Pandhari were promising for the development of genotypes with higher biomass. The genotype, C 152 is promising for pod development and seed growth characters having the lowest pod development, seed growth and lag periods, higher dry matter production and distribution in

component parts of plant, higher growth rates, high rate of photosynthesis, low rate of transpiration, high stomatal conductance, low water use efficiency, better performance for vegetative growth and source ability and generative growth and sink capacity and bio-chemical parameters. Therefore, C 152 might be considered as a best genotype in physiological point of view for improving the ontogenic characteristics in cowpea.

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1. INTRODUCTION

Ontogeny (also ontogenesis or morphogenesis) (*ontos* present participle of 'to be', *genesis* 'creation') describes the origin and the development of an organism from the fertilized egg to its mature form. In general terms, ontogeny is defined as the history of structural change in a unity, which can be a cell, an organism, or a society of organisms, without the loss of the organization that allows the unity to exist.

Within biology, ontogeny pertains to the developmental history of an organism within its own lifetime, as distinct from phylogeny, which refers to the evolutionary history of species. While developmental or ontogenetic processes can influence subsequent evolutionary or phylogenetic processes, individual organisms develop (ontogeny), while species evolve (phylogeny).

Legumes are plants that bear their seeds in pods. They differ markedly from grasses, cereals and other non-legume crops because much of the nitrogen they require is produced through fixation of atmospheric nitrogen by bacteria in nodules on their roots. As a result, legumes are rich in protein. World-wide more than 16,000 species of legumes are known, including herbs, shrubs and trees, but only about 200 are cultivated.

Pulses are the major sources of dietary protein in the vegetarian diet in India. Besides, being a rich source of protein, they maintain soil fertility through biological nitrogen fixation in soil and play a vital role in furthering sustainable agriculture. At present globally 60 million tonnes of pulses are produced annually from 70 million hectares. India is the largest producer with 33 per cent of global area contributing 22 per cent of the world's production. Normally the area under pulses in the country is

around 24.38 million hectares with a production of 14.52 million tonnes. The average productivity of the country is about 600 Kg/ha against the average global productivity of 857 Kg/ha (Kannaiyan, 1999).

The Cowpea (*Vigna unguiculata* (L.) Walp.) is one of the several species of the widely cultivated genus *Vigna*. Four cultivated subspecies are recognized:

1. *Vigna unguiculata* subsp. *cylindrica* Catjang
2. *Vigna unguiculata* subsp. *dekindtiana*
3. *Vigna unguiculata* subsp. *sesquipedalis* Yardlong bean
4. *Vigna unguiculata* subsp. *unguiculata* Black-eyed pea

Cowpea (*Vigna unguiculata* L. Walp.) is an annual legume and commonly referred to as southernpea, blackeyepea, crowderpea, lubia, niebe, coupe or frijole. It is originated in Africa and widely grown in Africa, Latin America, Southeast Asia and Southern United States.

Yield is a complex trait, governed by many traits and there is ample evidence to show that selection directly for grain yield in plants is not easy. Thus, any morphological character that is associated with higher seed yield or which makes a significant contribution to yielding ability would be useful in the improvement of grain yield. It is ultimately the number of pods, which is important for realizing higher productivity as evident from very high and positive association between these two traits (Mathur, 1995).

Legume seeds develop within the confines of an ovary-derived pod whose walls provide numerous functions for the seeds. The pod wall is a protective envelope to the developing seeds (Small and Brookes, 1982) acts as catchments transport link (Harvey, 1973; Setia *et al.*, 1987) and temporary reservoir for solutes mobilized

from vegetative parts to seeds (Willmer and Johnston, 1976; Atkins *et al.*, 1977; Thorne, 1979; Mounoury *et al.*, 1984) and if green and illuminated it functions significantly in photosynthetic fixation of CO₂ (Crookston *et al.* 1974, Quebedeaux and Chollet, 1975).

In pulses, carbon fixed by the outer pod wall may act as a long term carbohydrate reserve for remobilization during seed filling. This is consistent with changes in dry weight of the pod wall (Davies *et al.*, 1999) where starch is stored during early development of the pod and remobilized later in seed filling (Chopra *et al.*, 2000). This storage reserve would also be analogous to the starch stored in the seed coat of legumes earlier in development (Rochet and Butin, 1992) and polysaccharides stored in the stems of cereals which are later remobilized for grain filling (Wardlaw and Willenbrink, 2000).

Reproductive growth in grain crops is initiated by flowering and a period of pod or seed set. When flowering begins in pulses and fruit setting starts they provide apparently stronger sites for utilization of photosynthates. Nodules are possibly deprived of photosynthates and consequently start disintegrating at flowering and developing seed would have a heavy requirement of N₂, because they are rich in proteins (Sinha, 1974). The number of pods or seeds that the crop community produces is determined during this period and this number determines, in large part, the final grain yield.

The relationship between duration of the grain filling period and grain yield in corn was reported by Daynard *et al.* (1971) and Johnson and Tanner (1972) and defined effective filling period as final grain yield divided by average rate of grain dry weight accumulation during the linear period of grain formation, and hence is a relative measure of the length of the grain filling period.

They suggested that grain yield was a function of the rate and duration of dry matter accumulation in the grain. The fruit wall in pulses has high photosynthetic rate and high activity of carboxylase (Shanthakumari and Sinha, 1973).

The studies on pod ontogeny covers the events from appearance of floral bud, anthesis, setting of pods, development of pod shell, elongation and dry matter accumulation in pod shell, setting of seeds into pod and growth of grain in terms of length, breadth and width are very critical issues and perhaps the pivotal phenomenon in determining the yield.

Such studies have direct relevance with the ultimate yield of the crop. A thorough understanding of all such issues is essential and can perhaps make a break-through to remove the critical factors which limit the yield of cowpea.

Such types of studies are very meager in cowpea. On this background the studies were conducted under field conditions during *Kharif* seasons of 2009 and 2010 with the following objectives:

1. To investigate various events from setting of floral bud till maturity of pods in context of various growth characters in cowpea varieties.
2. To estimate pod and seed filling rates in context of length of pod and size of seeds in cowpea varieties.
3. To investigate total, actual and effective filling periods and their relation with actual and effective filling rates in cowpea varieties.
4. To assess growth rate and photosynthetic rate in cowpea.
5. Analysis of starch, carbohydrates and protein content during pod development in cowpea.

2. REVIEW OF LITERATURE

Ontogeny is the history of structural change in a unity, which can be a cell, an organism, or a society of organisms, without the loss of the organization that allows that unity to exist (Maturana and Varela, 1987). The events from setting of floral bud till maturity of pods in context of various growth characters, pod and seed filling rates in context of length of pod and size of seeds, total, actual and effective filling periods and their relation with actual and effective filling rates, plant growth analysis and nutritive changes during seed growth are reviewed in this chapter.

2.1. Pod ontogeny

Reproductive growth in grain crops is initiated by flowering and a period of pod or seed set. Reproductive plant organs impose a significant energy and carbon demand in relation to the total plant dry mass production (Bazzaz *et al.*, 1979), since significant quantities of assimilates are translocated from leaves to flowers and developing fruits (Pavel and DeJong, 1993). Several studies have reported that flowers, fruits, and pods of legumes have photosynthetic activity (Hansen, 1970; Crookston *et al.*, 1974; Flinn *et al.*, 1977), and so these reproductive structures should contribute with a fraction of the carbohydrates required for their development.

Many investigations on a number of aspects of the utilization of C, N, and water by developing fruits have been conducted on legumes, including bean (Crookston *et al.* 1974), pea (Flinn *et al.*, 1977; Flinn and Pate, 1968; Flinn and Pate, 1970; Harvey *et al.*, 1976 and Pate, 1984), soybean (Andrews and SvEc 1975; Layzell and Tarue, 1982), white lupin (Atkins and Flinn, 1978; Pate, 1984;

Pate *et al.*, 1977) as well as cowpea (Lentlemon *et al.*, 1981; Pate *et al.*, 1983; Peoples *et al.*, 1983).

Pod walls serve to protect the seeds during development (Small and Brookes, 1982), they are part of the source-sink pathway that delivers nutrients to the seed coat (Harvey, 1973; Setia *et al.*, 1987), and they can produce photosynthates (Willmer and Johnston, 1976; Atkins *et al.*, 1977) and/or metabolize storage products (Thorne, 1979; Mounoury *et al.*, 1984) for transfer to the seeds.

During early pod development stages, the dry matter accumulates in pod wall and then mobilize for grain development (Bhardwaj and Raju, 1972; Kumari and Sinha, 1972; Thorne, 1978 and 1979). In various legumes, developing pod walls act as a temporary reservoir of assimilates that are destined for transport to the developing seeds (Setia *et al.*, 1987).

The loss of moisture in maturing seed is an inherent phase of seed development (Kolhe and Chavan, 1964; Manohar and Sachan, 1974). Mayer (1973) supported the statement expressing that accumulation of dry matter with loss of moisture as the characteristic feature during seed development and maturation in any crop.

Aryeettey and Laing (1973) reported high heritability estimates for seeds per pod and pod length, suggesting that early generation selection for these traits will be successful.

Shanthakumari and Sinha (1973) reported that, the fruit wall in almost all pulses was found to have a high photosynthetic rate and high activity of carboxylase.

Formulae to calculate the partitioning and utilization of net photosynthate for synthesis of carbohydrates, oil, protein and other constituents was provided by Penning de Vries (1975).

Khanna-Chopra and Sinha (1976) suggested that, fruit wall and leaves translocate photosynthates to the developing fruits. In the early stages, translocation from the leaves was most efficient but in the later stages, more translocation occurred from the fruit wall as compared with the leaves.

Atkins *et al.* (1977) reported that, the pod wall of pea (*Pisum sativum* L.) contained up to 20% of the pod's chlorophyll, and was capable of fixing 66% of the CO₂ released during the photoperiod to the pod gas space by the seeds of a fully grown fruit.

Schou *et al.* (1978) suggested that, the flower and pod set is regulated by the supply of assimilates to developing flowers and pods.

Thorne (1979) studied that, maximum dry weight accumulated in pod wall when incipient canopy senescence probably would have otherwise precluded continued linear seed growth in soybean [*Glycine max* (L.) Merr.]. Pod walls were found to store and later redistribute starch, reducing sugars, and nitrogenous materials.

Fader (1985) assessed the relationships between carbohydrate pools of the soybean (*Glycine max* [L. Merrill) fruit and growth rate of seeds. Plants during midpod-fill were subjected to various CO₂ concentrations or light intensities for 7 days to generate different rates of seed growth. Seed growth rates ranged from 4 to 37 milligrams/day/fruit.

Kuo and Pate (1985) observed a mycelium-like network of internal phloem in the inner mesocarp of the lateral pod walls of the fruit of certain genotypes of cowpea [*Vigna unguiculata* (L.) Walp].

Ogunbodede and Fatula (1985) reported a higher estimate of narrow sense heritability for pod length and seed size.

Peoples *et al.* (1985) reported every 100 units by weight of carbon entering the fruit, 70% were finally incorporated into seeds, 10.3% remained as non-mobilizable material in pod walls, and the remaining 19.3% were lost in fruit respiration.

Thom *et al.* (1989) proposed that, the pod wall surrounding the developing soybean seed could serve as a diagnostic indicator of crop nutritional status and suggested to describe changes in pod wall composition during grain-fill, it appears that pod wall sampling offers an alternative or additional sampling interval in the evaluation of soybean nutrition.

Ntare (1991) observed significant differences among cultivars for ability to flower and set pods under high temperature conditions. The pattern of flowering and pod set showed that flowers formed in the first 10 days after initial flowering had the highest percentage pod set.

Habekotté (1993) studied pod formation, seed set and seed filling of winter oilseed rape (*Brassica napus* L.). A linear relationship was found between seed density and dry matter production of the crop during flowering.

Kharb *et al.* (1993) in agricultural crop and Natarajan (2000) and Vijayan (2002) in flower crops reported the cause for improvement in dry weight of the pod with advances in days of maturation.

Singh and Virmani (1996) developed a chickpea (*Cicer arietinum* L.) growth and development model (**CHIKPGRO**) from the hedgerow version of the groundnut model (**PNUTGRO**). The model predicted flowering, pod initiation, beginning of seed growth and physiological maturity.

The number of pods or seeds that the crop community produces is determined during pod and seed development period and this number determines, in large part, the final grain yield (Egli, 1998).

Milford *et al.* (1999) demonstrated that, the DM and N contents of the pod walls were maximum at the end of pod extension, but seeds contained only a third of their final DM and a quarter of their final N. Protein accumulation during the final stages of seed growth, therefore, depended on the remobilization of nitrogen from other plant organs, primarily the leaves and pod walls.

Lagunes-Espinoza (2003) investigated that, the proportion of pod walls, seed weight per pod and mean seed weight showed a mainly additive inheritance. Narrow sense heritability was higher for the proportion of pod walls than for the other pod components. The correlation between general combining ability (GCA) and parental phenotypic values was high for proportion of pod walls.

Furbank (2004) proposed that, the excised embryo, seed coat, and pod wall in chickpea are all photosynthetically competent however, the predominant role of the pod wall in refixation is supported by measurements of fixation of isotopically labeled CO₂, which show that more than 80% of CO₂ is fixed by this tissue when provided to the pod interior.

Sinhamahapatra (2004) revealed negative but insignificant correlation between proportion of pod wall and seed yield and direct effect of this trait on seed yield was also negative in mungbean. The analysis of variance of combining ability revealed significant variances for both GCA and SCA.

Egli (2005) suggested that, the flower production and seed set is a key phase in the yield production process.

Egli and Bruening (2005) suggested that, the distribution of flower and pod production during flowering may be an important determinant of pod and seed number in grain crops.

Li Wang and Grusak (2005) given a detailed structural and developmental characterization of *M. truncatula* pod walls and seed coats at the four time points (3, 6, 13 and 20 DPP) in which pods at 3 and 6 DPP reflect rapidly growing pod walls and the early emergence of developing ovules, 13 DPP reflect pods at the end of an early pause and 20 DPP have reached a plateau in fresh weight mass and seeds.

Kumar *et al.* (2008) reported that, the pod length (25 to 30 DAF), pod width (30 to 35 DAF), fresh weight of the developing pod (25 DAF), fresh weight of grains per pod (35 to 40 DAF) and dry weight of the developing pod and grains (40 DAF) were significantly increased with advancement of crop in garden pea.

Natarajan and Srimathi (2008) observed decrease in moisture content of pod with advancement in maturation correlated well with higher dehydration rate of pod as noted in small seeded agricultural and horticultural crops (Manohar and Sachan, 1974; Sabir-Ahamed, 1989). This could be due to the replacement of osmotic material by starch and other large molecules with low hydration capacity (Milthorpe and Moorty, 1979).

2.2. Pod and seed filling rates

In legume seeds, the active filling period begins when the pod wall was approximately reached its final size (Carlson, 1973): at this time the seed water concentration begins to decrease (Ney *et al.*, 1993; Munier Jolain *et al.*, 1993) and cell division in the embryo stops (Ney *et al.*, 1993; Egli *et al.*, 1981). The large seeded genotypes have the largest seed growth rate (Egli *et al.*, 1981, Munier Jolain and Ney, 1995).

Modern cultivars tend to have a longer SFP (Seed filling period) than older ones (Gay *et al.*, 1980; McBlain and Hume, 1980), and the SFP can be changed by selection (Smith and Nelson, 1986a). Seed growth rate (SGR), or the' accumulation of seed dry matter per unit time, also varies among strains (Egli *et al.*, 1984; Kaplan and Koller, 1974) and has been positively correlated with final seed weight (Egli *et al.*, 1984), but rarely with yield, because of an inverse correlation with seed number (Shibles *et al.*, 1975).

SFP and SGR are affected by temperature (Egli and Wardlaw, 1980; Hesketh *et al.*, 1973), moisture stress (Meckel *et al.*, 1984), the source/sink ratio (Egli *et al.*, 1985) and photoperiod (Fuki and Yarminizeu, 1952; Johnson *et al.*, 1960; Nagata, 1958; Raper and Thomas, 1978; Thomas and Raper, 1976).

Reproductive phenological events or R-stages have been used for estimating both *SFP* and *SGR* (Niwa, 1985). *SFP* and *SGR* vary among different combinations of maturity or stem termination alleles in plants exposed to different photoperiods and temperatures (Bernard and Weiss, 1973; McBlain *et al.*, 1987; Wang *et al.*, 1987).

The environmental stresses applied before the seed fill (Jones *et al.*, 1984; Outtar *et al.*, 1987) reduce individual seed growth rate compared to control plants in maize. These reductions in individual

seed growth rate are irreversible even if the assimilate availability for filling seeds is increased during the seed filling period (Jones and Simmons, 1983). Conversely, the reduction in assimilate availability during seed filling has no effect on the individual seed weight (Jones *et al.*, 1984); water stress (Outtar *et al.*, 1987) ; leaf removal (Jones and Simmons, 1983).

Genotypic variation during the pod development period is observed in cowpea, which is positively associated with individual seed weight (Wien and Ackah, 1978). For very small seeds (50 mg/seed), the pod development period was 17 days, whereas with moderately large seeds (200 mg/seed), the pod development period was 21 days.

Egli *et al.* (1985) observed that, fruit and leaf removal during the early pod filling period, an increase and a decrease in seed growth rate, in indeterminate and determinate soybeans, respectively.

Dumbre *et al.* (1983) reported broad sense heritability estimates of 52 and 42% for maturity and pod filling period, respectively.

Emeberi and Obisesan (1991) reported narrow sense heritability (h^2) of 52% for days to pod filling period.

Euwens and Schwabe (1975) demonstrated close relationship between changes in extractable amounts of gibberellins (GA₂₀), auxins (methyl 4-chloroindol-3yl acetate and probably 4-chloroindol-3yl acetic acid), and abscisic acid, and changes in growth rates of both the pod wall and seeds.

McCloud *et al.* (1980) demonstrated that, longer filling period can be achieved in two ways, by a lower individual pod filling rate or by a longer seed size with a same pod filling rate.

Smith and Nelson (1986b) suggested that, seed filling period (SFP) and seed yield are positively related in soybeans [*Glycine max* (L.) Merr.]. It may suggest a positive relationship between SFP and yield and that progress for yield may be made by selecting for SFP.

Babu and Kailasum (1988) studied that, the pod filling rate or duration of pod filling greatly decide final pod weight in greengram and blackgram. The effective pod filling duration is only 16 days in both the crops.

Guffy *et al.* (1991) studied seed growth rate and duration of growth for different soybean [*Glycine max* (L.) Merr.] cultivars and isolines differing in maturity and stem termination under field conditions. The final seed weight, divided by its growth rate during the linear phase of dry matter accumulation, or the 'effective filling period', correlated best with yield.

Ntare (1991) studied the variation in reproductive period and grain yield of cowpea under high temperature condition and reported considerable variations among cultivars in the duration of reproductive period, crop growth rate and partitioning of photosynthates.

Munier-Jolain and Ney (1995) stated that, the variations in individual seed weight among different environmental situations are mainly due to variation in seed growth rate, even if the duration of seed filling varies.

Munier-Jolain *et al.* (1996) analyzed final seed weight as the product of seed growth rate and duration of seed filling, both of which can vary with environment. In indeterminate soybean (*Glycine max* L. Merr.), seed filling is often considered to be limited by the translocation of N compounds from vegetative organs.

Dracup and Kirby (1996) investigated relationships in the patterns of pod and seed filling on the branch orders and described the development and morphology of pods and seeds. Despite the sequential setting of pods, their phases of rapid growth were almost synchronous and they reached maturity at almost the same time.

Munier Jolain *et al.* (1998) stated that, the maximum growth rate of seeds was achieved regardless of the intra plant competition level, and the duration of seed growth was shortened if the photosynthetic activity was not sufficient to fulfill the assimilate demand of filling seeds.

Poggio *et al.* (2005) stated that, the duration of the seed-setting phase was estimated from records of the progress of flowering on the main stem and an estimate of the thermal time from flowering at which the uppermost reproductive node reached the final stage of seed abortion.

Mokhtassi-Bidgoli *et al.* (2007) reported differences among safflower genotypes for rate of seed filling and effective seed filling duration were significant and differences in seed yield could be attributed to differences in the rate of seed filling.

Kaur *et al.* (2008) reported that, the seed growth rate, seed fill duration, seed number, and average seed weight and size decreased greatly in the plants cold stressed at the late pod filling stage than those stressed at the early pod filling stage.

Koutroubas and Papakosta (2010) used cubic polynomial model for seed filling rate ($\text{mg head}^{-1} \text{ day}^{-1}$) and duration (days) and indicated that this model could be successfully used to simulate the seed growth and to estimate the seed filling parameters in safflower genotypes with high coefficients of determination (r^2) that ranged from 0.901 to 0.999.

2.3. Actual and effective pod/seed filling and lag periods

Daynard *et al.* (1971) defined effective filling period as final grain yield divided by average rate of grain dry weight accumulation during the linear period of grain formation, and hence is a relative measure of the length of the grain filling period. The effective filling period duration (EFPD) was unaffected by planting density.

Johnson and Tanner (1972) suggested that, grain yield was a function of the rate and duration of dry matter accumulation in the grain. The technique of calculating these two components was based on regression analysis of yield over time. The duration of the actual grain filling period can be calculated from the final yield plus two or three sampling dates between three and six weeks after silking.

Sinha (1974, 1977) reported decline rate of photosynthesis following early fruit development which is associated with decreased RuBP carboxylase activity in cowpeas, mungbean and chickpeas.

Wien and Ackah (1978) demonstrated that, yield of grain legumes is governed by the length of the reproductive period which in turn depends on the time from anthesis to maturity of individual pods (pod development period). To determine genetical and environmental effects on pod development period (PDP) in cowpea (*Vigna unguiculata* L. Walp.), individual flowers were tagged at anthesis and the time to pod maturity noted in several experiments. In two field experiments, PDP of 91 and 65 cowpea lines, respectively, varied from 17 to 24 days, and was positively correlated with seed weight. Long PDP was also associated with rough seed coat texture. Dry matter accumulation by individual

Pods of three cultivars differing in PDP determined in a pot experiment showed differing durations of pod and seed growth.

Chaturvedi *et al.* (1980) reported that, the fruit development in cowpea being fast, it took only 19 days from anthesis to fruit maturation. Dry matter accumulation in fruit wall increase progressively from anthesis to the 13-15th days, whereas, nitrogen accumulation continued upto the 11th day in both fruit wall and seeds.

McCloud *et al.* (1980) reported that, a longer filling period can be achieved in two ways; by a longer individual pod filling rate or by a longer seed size with a same pod filling rate.

Chitnis and Janadagni (1982) investigated the association of seed filling parameters with yield and other characters in black gram.

Bangal and Patil (1983) reported that, after anthesis the pod and the grain development in chickpea were determined by the rate and duration of photosynthetic area.

The seed filling period (SFP), or the duration of dry matter accumulation in seeds, varied greatly among soybean strains (Egli *et al.*, 1984; Reicosky *et al.*, 1982) and has been associated with increased yield (Dunphy *et al.*, 1979; Gay *et al.*, 1980; Hanway and Weber, 1971; McBlain and Hume, 1980; Smith and Nelson, 1986b) and final seed weight (Egli *et al.*, 1984).

Variations in seed filling duration among genotypes and among environmental conditions have been reported (Pfeiffer and Egli, 1988; Dumoulin, 1994), though seed size is rarely correlated with seed filling duration (Pfeiffer and Egli, 1988).

Khanna-Chopra and Sinha (1988) introduced relevance of plant processes in connection with plant type for understanding the causes of limitations of the yield in pulses.

Fountain *et al.* (1989) reported that, the seed growth was at the expense of pod dry weight (DW) reserves. The transfer activity was apparent only within the period 10 to 30 days after anthesis (DAA) with maximal activity between 15 to 20 DAA. This period corresponds to maximum pod growth and the attainment of maximal DW.

Summerfield *et al.* (1989) emphasized that, an appropriate phenology relative to the growing season is important for improved productivity in the environments to a drought stress and temperature extremes are expected. They considered the rate of progress towards phonological events for describing quantitative responsiveness of germination and flowering to photo-thermal conditions.

Naik (1990) studied various attributes of pod development in eight cowpea genotypes and reported that the pod development period varies in the range of 21 to 29 days. The effective seed filling period was in range of 12 to 14 days.

Jamadagni *et al.* (1995) characterized nine field grown cowpea genotypes was using plastochron index. The population under study completed a vegetative phase within 50 days and exhibited flower initiation in 55 days. The maturity period was found to be a sum of the periods for plastochron completion, lag I, pod development and lag II. Lag I and Lag-II periods existed due to variation in the relative sensitivity of successively formed leaves to the normal inductive conditions. A high genotypic variation for the

two lag periods indicated a scope for designing efficient plant architecture of cowpea either for grain or for vegetable purpose.

Chudasama and Thaker (2007) divided seed development into four distinct phases (i) cell division, (ii) cell elongation, (iii) dry matter accumulation and (iv) cell maturation. Similar growth phases are described for seed development in cotton (Rabadia *et al.*, 1999) and hibiscus (Thaker, 1999).

2.4. Growth rate and photosynthetic rate

2.4.1. Dry matter production and it's distribution in component parts of plant

All the physiological processes, both anabolic and catabolic result into a net balance or accumulation of dry matter and hence, the biological productivity of plants is judged from it's actual ability to produce and accumulate dry matter. In a sense, the growth of the plant is nothing but the progressive accumulation of dry matter.

Ezedinma (1966) observed that, an optimum plant size of cowpea was attained at about flower initiation stage and concluded that, subsequent vegetative growth might interfere with yield and also affect seed quality.

Ojehomon (1970) studied the growth parameters of cowpea genotypes in field as well as greenhouse. Cultivar New Era with the highest seed yield had the largest vegetative dry weight, leaf area and leaf area duration, followed by Mala, with Azuki always least in each parameter.

The rate of dry matter production in vegetative parts decreased slightly which was claimed to be due to the development of inbuilt mechanism that involved in the disorganization of cell

organelles in the few days after physiological maturity (Mathews, 1973).

Chaturvedi *et al.* (1980) reported higher grain yield in the indeterminate varieties of cowpea. Pod development was completed in 19 days and the rate of dry matter accumulation during the peak period of growth was as high as 120 mg/day per fruit.

Egli *et al.* (1985) suggested that variation in fruit and seed number may be more closely related to variations in crop growth rate than to variations in the allocation of assimilate between vegetative and reproductive plant parts.

Jagamohan Rao and Singh (1985) reported that, pod dry weight went on increasing from 45 days onwards till the maturity. The result was also indicated that for an every unit of increase in dry weight there was proportionate increase in seed yield.

Thandapani and Rao (1986) reported that, dry matter accumulation in stem was higher during vegetative stage of the crop in high yielding varieties and lower in medium and low yielding varieties of mungbean.

Gill *et al.* (1988) in the field experiment on chickpea genotypes conducted at PAU, Ludhiana (Punjab) reported that, dry matter accumulation in leaves and stem was low at initial stage which increased later on upto 90 days after sowing. However, at harvest decline in dry matter accumulation of root leaf and stem was observed.

Natarajan and Palanisamy (1988) concluded that, maintaining a fairly higher total dry matter production with stimulus enhancement of harvest index may contribute to increased seed yield in mungbean.

Bisht and Chandel (1989) observed that, dry matter and its rate of accumulation increased with plant age in soybean.

Kumari and Singh (1990) reported linear increase in dry matter production from 30 to 90 days after sowing in Spanish and Valencia and upto 110 days in Virginia groundnut. Dry matter accumulation was more in vegetative parts upto 90 DAS and after that it was more in pods.

Reddy *et al.* (1990) reported that, total dry weight in green gram and black gram cultivars showed a continuous increase throughout the crop growth period because of phosphorus application @ 25 kg/ha as basal dose and 25 kg at the time of flowering.

Singh *et al.* (1991) concluded that, the dry matter of chickpea showed declining trend in late sowing. The dry matter of leaves, stem, roots, pods per plant of first sowing differed significantly from the second and third sowing.

Jirali *et al.* (1994) reported the positive relationship between seed yield and harvest index was indicative of better dry matter partitioning into economically useful parts in chickpea. The association between dry matter production and seed yield became stronger in the late part of crop growth.

Sahane *et al.* (1995) observed that, the total dry matter accumulation and daily rate of dry matter production were positively correlated with grain yield at different stages of crop growth in horse gram.

Ganguly *et al.* (1999) estimates correlation regression, direct and indirect effects and association (%) between seed yield and different traits at various phenological stages revealed differential response trend of traits with yield in chickpea.

Kalpana *et al.* (2003) studied physiological basis of yield determination in 12 genotypes of cowpea and found significant positive correlation with total dry matter, leaf area index and biomass duration thereby indicating its importance in the production of leaf area and TDM.

Bhat *et al.* (2002) found that, delay in sowing showed decline in dry matter accumulation in field pea.

Omoigui (2006) showed that, there was considerable variation among cultivars for duration of reproductive phase and rate of photosynthate partitioning.

Ghodke *et al.* (2008) evaluated 13 genotypes of chickpea under irrigated and moisture stress conditions in which the change in dry matter production and their distribution in roots, leaves, stem and pods showed independent behaviour over crop growth period.

2.4.2. Vegetative growth and source

The vegetative phase governs the overall phenotypic expression of the plant and prepares the plant for next important reproductive phase. The root, stem, branches and leaves, all these parts constitute vegetative phase and perform specific functions.

Woodstock and Combs (1964) coined root length and shoot length as a measure of seedling vigour as they reveal the performance of the seed under given environmental conditions. The root and shoot growth increased with advances in maturation (Burries *et al.*, 1973) which was in coincidence with stages of dry weight of pod /seed and seed germination.

Watson (1956) concluded that, yield was dependent on size, efficiency and duration of photosynthetic system and hence, leaf

area and leaf area duration contributed more to biological yield than the NAR. The importance of leaf area has been apparent through several earlier studies (Muramoto *et al*, 1965; Shibles and Weber, 1965).

Tikka and Asawa (1981) observed in 12 indigenous and 13 exotic genotypes of cowpea that, the yield was correlated with plant height.

Pal (1988) reported significant differences for plant weight and height, leaf and branches number and dry matter production in 18 cultivars of cowpea grown for forage.

Shinde and Saraf (1991) noted the positive and significant correlation of seed yield with leaf area in field experiment on chickpea genotypes at IARI New Delhi and.

Panwar *et al.* (1995) reported positive association of plant height with seed yield of chickpea.

Jadhav *et al.* (1995) showed that, delay in sowing date reduced plant height from 45.77 to 36.00 cm over optimum sowing in cowpea. Primary and secondary branches differed significantly from optimum sowing and in late sowing.

Naidu *et al.* (1996) reported that, number of branches, clusters, pods/plants, seeds/pod, seed weight and seed yield were found high in determinate types while plant height and pod length were found high in indeterminate cowpea. The determinate types were early in flowering and maturity compared to the indeterminate types.

Silk (1997) defined growth in plants as an irreversible increase in volume. The largest component of plant growth is cell expansion driven by turgor pressure. During this process, cells

increase in volume manifold and become highly vacuolated. However, size is only one criterion that may be used to measure growth.

Hozayn (2007) studied the performance of 4 mungbean genotypes at different growth stages as well as yield and its components under late sowing condition. The results indicated that genotype King surpassed the other genotypes in seed yield, no. of seeds/plant, harvest index and 100-seed weight.

Biradar *et al.* (2007) concluded that, the trait of interest yield is positively and significantly associated with its contributing morphological characters of cowpea. Highest yield was realized through pod number and indirectly by branch number.

Sangakkara (2008) concluded that, growth and yield of cowpea plants grown from small seeds with a high conductivity of their leachates were significantly lower than those grown from large seeds.

2.4.3. Phenological Characters

The phenology of plant constitutes the starting point of growth and development towards reproductive phase. From yield point of view, this phase assumes significance as the sink lies in reproductive parts. Hence, the observations were made on various aspects of phenology i.e. days to appearance of first flower bud, days to initiation of flowering and days to maturity.

Yield potential and early flowering are the two major components of drought escape in lentil and chickpea (Saxena *et al.*, 1993; Silim *et al.*, 1993; Silim and Saxena 1993). The crop has to some extent buffered against drought events and stability of yield is improved (Turk *et al.*, 1980). The flexibility increased if podding can

begin from early growth stages, at more basal nodes (Saxena *et al.*, 1993).

The degree of phenological plasticity can be controlled by photothermal effects, which are major components of G x E interactions in legumes (Roberts *et al.*, 1993). There are many subtle effects of temperature and photoperiod affecting phenology and partitioning in legumes, about which we are only just beginning to understand (Wallace *et al.*, 1993).

Briggs and Knowles (1967) put forward the view applies to cowpea where a period of vegetative growth is followed by the production of flowers and pods after which the plant dies.

Erect indeterminate cowpeas are able to produce two distinct flushes of pods (Gwathmey *et al.*, 1992). The crop is harvested after producing either only the first flush of pods or after accumulating both flushes of pods (Hall and Frate, 1996).

Nielsen and Hall (1985a) reported that, the period from anthesis to maturity of individual pods decreased linearly from 21 days with minimal night temperature of 15.5°C, typical of cool subtropical zones, to 14 days with minimal night temperature of 26.60°C, which is typical of hot tropical environments (Nielsen and Hall, 1985b).

Wien and Ackah (1978) showed in very small seeds the pod development period was 17 days, whereas with moderately large seeds the pod development period was 21 days.

Craufurd *et al.* (1997) reported that, the rate of production of nodes is the same as the rate of production of leaves. Leaf appearance rate (RLA, in day⁻¹) in cowpea has exhibited a linear dependence on mean air temperature above a base temperature (T_b), with no effect of photoperiod.

Singh and Saxena (1981) reported that, days to flowering were affected by planting date in green gram, black gram, cowpea and pigeon pea genotypes.

Ramachandran *et al.* (1982) reported that, the major parts of total variation in yield for pods per plant and internodes length was largely due to genetic causes and obtained high genetic variance for days to flower and harvest in cowpea.

Wanjari (1988) observed that, flowering had negative effect and also negative association with yield of black gram hence early flowering and maturity are desirable traits to get higher yield.

Patil and Bhapkar (1987) showed positive correlation between days to flowering and maturity which was significant at genotypic level. Days to flowering with number of primary branches and days to maturity with number of secondary branches showed positive and significant correlation in cowpea.

Jadhav *et al.* (1995) indicated the role of day length, night temperature and humidity in flowering and maturity of cowpea.

Natarajan and Srimathi (2008) revealed that, seeds of *petunia* attained physiological maturation at 25 DAA with the physical indices of maximization of fresh and dry weight of pod and seed and pod length and the visual indices as turning of pod to yellowish brown colour and the seed to dark brown.

2.4.4. Growth Parameters

In crop science, the growth analysis technique aids in identifying and defining an ideal plant type or through management practices. This would be vital to the breeder as well as agronomist in tailoring suitable genotype or management technology for boosting up the growth and yield factors of the crop.

Briggs *et al.* (1920) defined absolute growth rate (AGR) as daily increment in dry matter over a given period. The AGR gives general idea regarding the pattern of growth at different growth stages. Blackman (1919) derived concept of relative growth rate (RGR) as an overall measure of rate of increase in dry weight per unit dry weight. Hsu (1977) in berseem and soybean, Shivkumar and Shaw (1977) in soybean who reported declined RGR with the advancing age of the crop. Watson (1947) introduced the concept of leaf area index (LAI) as one of the most important growth parameter. The LAI gives an idea about the size of the photosynthetic system. Gregory (1926) had given the idea about net assimilation rate (NAR) is the rate of increase in dry weight per unit leaf area, assuming that both dry matter and leaf area increase exponentially. Nichiporovich (1964) and Watson (1958) have reported the decline in NAR with increase in LAI. Specific leaf area (SLA) is the dry matter production per unit leaf area. The concept developed by Radford (1967) is very useful to understand the ability of leaf to photosynthetic assimilation on per unit basis. The concept of leaf area ratio (LAR) owes its basis to Whitehead and Myrescaugh (1962) and concluded that this ratio of relative increment in leaf area and dry weights of the plant would help in understanding the growth complex of plants.

Radford (1967) derived the growth analysis formulae in most common use and all the necessary assumptions involved in their derivation are explained. A distinction is made between the traditional techniques which involve the calculation of mean growth rates etc over time periods and an alternative approach which enables a continuous trace of change with time to be made.

Plant growth analysis is an explanatory, holistic and integrative approach to interpreting plant form and function. It uses

simple primary data in the form of weights, areas, volumes and contents of plant components to investigate processes within and involving the whole plant (Evans, 1972; Causton and Venus, 1981; Hunt, 1990). From its origins at the end of the nineteenth century, plant growth analysis first illuminated plant physiology, then agronomy and now physiological and evolutionary plant ecology (Garnier *et al.*, 1999).

Ojehomon (1970) studied the growth parameters of cowpea genotypes in field as well greenhouse in which differences in relative growth rate, net assimilation rate or leaf area ratio was too small to account for varietal differences in seed yield.

Brakke and Gardner (1987) evaluated growth parameters influencing seedling and juvenile growth of pigeonpea compared to grain legumes, cowpea (*Vigna unguiculata* L.) and soybean [*Glycine max* (L.) Merr.]. Relative DM yield was 100, 64, and 27%, respectively. However, relative leaf and plant growth rates during the time course were significantly greater for pigeonpea than for soybean and cowpea.

Poorter (1989) proposed a method of calculating relative growth rates (RGR) and net assimilation rates based on the fitting of a polynomial through the relative growth rate values calculated by the 'classical' approach rather than through the in-transformed plant weights as in the 'functional' method.

Anten and Ackerly (2001) estimated absolute growth rate (g day^{-1}), relative growth rate (RGR, $\text{g g}^{-1}\text{day}^{-1}$), net assimilation rate (NAR, $\text{gm}^{-2} \text{day}^{-1}$), leaf area ratio (LAR, m^2g^{-1}), fraction of newly assimilated mass that is allocated to leaf lamina production (flam , g g^{-1}), and daily fractional change in the average specific leaf area of

plants ($r \text{ day}^{-1}$). These parameters are determined by means of interactions.

Bastos *et al.* (2002) adapted the CROPGRO model, which is part of the DSSAT system, for simulating the cowpea (*Vigna unguiculata*) growth and development under soil and climate conditions of the Baixo Parnaíba region, Piauí State, Brazil. In the CROPGRO, only input parameters that define crop species, cultivars, and ecotype were changed in order to characterize the cowpea crop.

[Kavurmaci](#) *et al.* (2010) used 8 forage plants (C_3 type) and analyzed importance of the growth parameters, relative growth rate (RGR), net assimilation rate (NAR), leaf area rate (LAR), leaf weight rate (LWR) and root weight rate (RWR). A large variation in physiological characters between species was observed.

2.4.5. Photosynthetic rate, transpiration rate, stomatal conductance and water use efficiency

Genotypic differences in the potential grain yield of cowpea have been positively associated with leaf stable carbon isotope discrimination (D), indicating that more productive genotypes had higher internal carbon dioxide concentration in their leaves (Hall *et al.*, 1997; Condon and Hall, 1997). The positive association between grain yield and D has been observed in other crop species with C_3 photosynthetic metabolism (Hall *et al.*, 1994; Condon and Hall, 1997). The higher D in more productive genotypes of cowpea, cotton (*Gossypium barbadense* L.), and wheat (*Triticum* sp.) was probably due to their having more open stomata, which could have resulted in greater rates of photosynthesis due to diffusion effects (Condon and Hall, 1997), or beneficial effects on the plant resulting from greater evaporative cooling (Lu *et al.*, 1998). An alternative explanation for the higher grain yields in cowpea, cotton, and wheat

is that D has also been positively correlated with HI (Mene´ndez and Hall, 1996). The evolutionary basis of the positive genotypic association observed between biomass production and stomatal conductance with several crop species has been discussed by Condon and Hall (1997). Interestingly, F1 hybrids of cowpea usually have strong early vegetative vigor, as well as D values that are higher than midparent means under well-watered field conditions (Ismail and Hall, 1993, Ismail *et al.*, 1994).

In legumes, net pod photosynthesis is generally lower and, in chickpea, rates are generally less than 5% of that in the subtending leaf (Leport *et al.*, 1999; Ma *et al.*, 2001). However, in dicots, the role of photosynthesis in reproductive structures to reduce respiratory CO₂ loss has also been emphasized (Flinn *et al.*, 1977; Atkins *et al.*, 1977; King *et al.*, 1998; Ma *et al.*, 2001).

Shanthakumari *et al.* (1973) revealed that, the photosynthesis and photosynthetic enzymes during growth and development of Bengal Gram fall after flowering, even in newly formed leaves.

Littleton *et al.*, (1981) demonstrated that, most leaves had maximum rate of photosynthesis (P_m) of about 1.4 mg CO₂/m²/sec and maintained this value for 20 days from full expansion. Early leaves had slightly slower rates. P_m decreases when leaf temperature exceeded 35°C. The maximum efficiency of photosynthesis was about 2 g CO₂/E (0.045 mol CO₂/E). Maximum efficiency of photosynthesis decreased with temperature for leaves, but increased for pods.

Pandey *et al.* (1981) the leaf area index governs the photosynthetic productivity and is negatively correlated with dry matter and pod number per plant but negatively correlated with pod length and yield in cowpea.

Spaeth and Sinclair (1983) reported that, diurnal temperature fluctuations induced change in soybean pod, carbon exchange rate (CER). The CER appeared to depend linearly on temperature.

Bangal and Patil (1983) reported that, the grain filling depends upon the supply of assimilates from both current photosynthates and reserve assimilates from different plant parts.

Grover and Sinha (1985) studied net photosynthesis rate, ribulose-1,5-bisphosphate carboxylase activity, ribulose-1,5-bisphosphate carboxylase, protein and total chlorophyll content in leaves which subtend the pods vis-a-vis the pattern of pod, pod wall and seed growth were analyzed in chick pea.

Gupta *et al.* (1989) noted that, the variation in leaf photosynthetic rate and specific leaf weight at 50 per cent flowering and 20 days after flowering reported highest variation in leaf photosynthetic rate (43 %) and specific leaf weight (22.8 %).

Araus *et al.* (1993) claim that, up to 76% of grain carbon can be derived from ear photosynthesis in cereals while in dicots there is considerable interspecific variation in the photosynthetic capacity of reproductive structures.

Armstrong *et al.*, (1994) studied to measure the efficiency of plant water use in relation to dry matter production provided closely similar rankings of genotypes.

Poorter *et al.* (1994) the herbaceous species with a high rate of transpiration per unit leaf area had a higher C_i/C_a ratio and lower water use efficiency of photosynthesis.

Ismail *et al.*, (1994) in cowpea abscisic acid content was positively correlated with water use efficiency, biomass, water use and leaf area for genotypic effects.

Singal *et al.* (1995) reported that, the rate of pod photosynthesis and activities of photosynthetic carbon reduction cycle enzymes were higher in younger pods but sufficiently high levels were retained up to 40 days after anthesis in Toria. The rate of dark $^{14}\text{CO}_2$ fixation in seeds increased up to 21 days after anthesis and declined thereafter but maintaining sufficiently high rates till 35 days after anthesis.

Mythili and Nair (1996) observed decline in rate of photosynthetic after flowering and during pod development in chickpea.

King *et al.*, (1998) reported rates of net CO_2 fixation as high as 35% that found in leaves on an area basis and equivalent on a chlorophyll basis in oilseed rape (*Brassica napus* L.) pods.

Koesmaryono *et al.* (1998) observed increase in specific leaf area (SLA) and the decrease in nitrogen content per leaf area unit contributed to the P_n reduction of soybean plants grown under low irradiances. Though E of the plants grown under different irradiances differed less markedly than P_n , the water use efficiency declined from I100 to I25.

Bhattacharya and Singh (1999) concluded that, significant correlation photosynthetic rate and allied parameters had with yield at growth stages.

Thakur and Kaur (2001) photosynthetic rate was significantly higher in most of the tree species from July to November. Transpiration rate was higher in multipurpose tree species. Water use efficiency (WUE) has been found to be low for all the 12 MPTs where values ranged between 0.0031 and 0.0870 with the maximum WUE in Albizia and the minimum in Morus.

Kalpana *et al.* (2003) indicated that, the determinate genotypes had higher value of photosynthetic rate (P_n), transpiration rate (TR), stomatal conductance (SC) as compared to indeterminate genotypes. It was also observed that all these parameters were at flowering stage and declined at pod development stage.

de Lemos Filho and dos Santos Isaias (2004) reported that, the frequency of stomata on the leaflets was 20 times higher than that observed on the fruits, and this was related with the lower conductance of the fruits in comparison with the leaflets.

Souza (2004) studied the responses of photosynthetic gas exchange and chlorophyll fluorescence along with changes in carbohydrate and proline levels were in cowpea (*Vigna unguiculata*) during water stress and recovery. Decreased CO_2 assimilation rates during water stress were largely dependent on stomatal closure, which reduced available internal CO_2 and restricted water loss through transpiration.

Vijaya Kumar and Vanaja (2004) in castor bean the study indicated that net photosynthetic rate is positively correlated with light intensity and negatively with vapour pressure deficit.

Ravindra *et al.* (2008) studied ontogenetic changes in growth and the diurnal changes in net photosynthetic rate (P_N) and stomatal conductance in two peanut cultivars of different habit groups. The differences in growth and P_N of the cultivars were significant after the onset of reproductive sink. Therefore, the screening for higher P_N has to be made at the pod-filling phase and between 09.00 and 10.00 of the day.

Patel *et al.* (2008) reported that, the cowpea cultivar GC-4 had highest and Pusa Falguni had lowest water use and water expense efficiency.

Makoi *et al.* (2010) showed significantly higher photosynthetic rates, stomatal conductance and transpiration in leaves of plants at low density and in monoculture due to greater chlorophyll (Chl) levels relative to those at high density and in mixed culture.

2.4.6. Generative growth and sink

The assessment of the variation in the yield-determining quantitative traits of crop has become primary in the breeding for yield. Yield improvements have been achieved through directional selections for yield - contributing traits (Akbar and Kamran, 2006). Pods, seeds yield and 100 seed weight have been reported among the prominent grain yield determinants of cowpea (Brolmann and Stoffella, 1986; Siddique and Gupta, 1991). They have been found to have reliable predictability on grain yields in grain legumes, such as: mungbean, pea and pigeon pea (Singh and Malhotra, 1970; Narsinghani *et al.*, 1978; Dani, 1979). Many past studies on stability have often been on polygenic traits, most especially, the yield; the genetic performances of other quantitative traits are likewise influenced by the environment (Siddique and Gupta, 1991; Aremu *et al.*, 2007). Enhancement of pod set in green beans has been correlated with hormonal balance [Ofir *et al.*, 1993]. Enhancing plant growth and production of green bean was achieved by many techniques such as improving fertilization regimes [Abdel-Mawgoud *et al.*, 2005] and irrigation [Abdel-Mawgoud, 2006].

Bhaskarain *et al.* (1980) reported that, in the high yielding parents of cowpea, pods per plant and 100 seed weight was most important yield contributing characters.

Imrie and Butler (1983), yield per pod, harvest index and yield per geometric mean of total number of pods and forage yield, which designate the geometric yield efficiency index, were independent of the size of plants in a plot and had low variability in determinate cowpeas.

Pookpakdi and Nanus (1983) reported that, high yielding varieties had high rate of dry matter accumulation in the seed of mungbean. While Shrinivasan *et al.*, (1985) observed that, dry weight of pod as well as seed increased in a sigmoidal pattern in mungbean.

Khan and Stofella (1985) concluded that, pod number per plant was single component most strongly and consistently related to seed yield while seeds per pod and seed size provided little additional indication of crop yield in cowpea.

Siddeswaran *et al.* (1990) reported that, grain yield of summer and *kharif* cowpea was increased with application of growth substances at lower concentration but the number of pods per plant, number of seeds per plant, pod length and 100 grain weight did not differ significantly.

Sarkar (1990) in field experiment of pea reported that, plant height, pod number per plant and total above ground dry matter production (TDMP) exhibited positive significant association with grain yield. While, grain number per pod, 100 grain weight and harvest index has non-significant correlation.

Pekşen (2007) determined the temporal distribution of the flowering, pod number and seed per plant, pod and seed setting performance and their relationships to seed yield in common bean (*Phaseolus vulgaris* L.).

Damarany (1994) reported broad-sense heritability for seed weight/plant was 94.4%, 85.9% for pods/plant, and 83.3% for 100 seed weight in cowpea.

Menendez and Hall (1996) studied the heritability of harvest index in two crosses (TVx 309 $\times$ Prima and TVx 309 $\times$ CB 46) of cowpea. The broad-sense heritability for this trait was 38% and 58% in the two crosses, respectively.

Pathmanathan *et al.* (1997) shown the broad-sense heritability for pod weight was 84% and the narrow-sense heritability was 75% indicating good genetic variability for effective selection.

Sangwan and Lodhi (1995) studied heterosis for yield and yield components in cowpea varieties. Better parent heterosis was recorded upto 84.0%, 81.6%, 35.6%, 20.4% and 36% for seed yield/ha pod/plant, pod length, seed/pod and seed weight/plant, respectively.

Arvindhan and Das (1996) reported 215% heterosis for seed yield in the cross CS 55 $\times$ CO4.

Bhor *et al.*, (1997) studied P₁, F₁, and F₂ populations of 14 crosses and observed 63.8% better parent heterosis for seed yield in the cross V240 $\times$ VCM8. They further observed that the heterosis was 4.3% for plant height and 91.52% for days to maturity.

Bhushana *et al.* (2000) estimated a midparent heterosis of 171.5% for number of secondary branches/plant, 11.5% for pods/plant, 105.3% for seed yield/plant, 75.5% for primary branches/plant, 30.31% for pod length, and 20% for 100 seed weight in cowpea.

Peksen (2004) found positive and highly significant correlations ($P < 0.01$) between fresh pod yield/plant and fresh pod harvest period, number of pods/plant, average pod weight, length and width. There were also positive and significant ($P < 0.05$) correlations among fresh pod yield/ plant, number of branches/ plant and pod thickness.

Vural and Karasu (2007) showed factor analysis based principal component (PCA) of two factors, representing 99.13 % of the total variation. PC1 explaining 98.69 % of the total variance is highly correlated with seed and pod size factors. PC2 may be considered as the time of vegetation time and yield per plant.

Omoigui (2006) showed genotypic coefficients of variation for days to first flower, 100-seed weight, plant height, and harvest index. Broad-sense heritability estimate (h^2) was 98.9% for 100-seed weight, 94% for duration of reproductive phase, 84.5% for days to first flower, 83.9% for days to maturity, and 77.3% for harvest index.

Peksen (2007) determined the temporal distribution of the flowering, pod number and seed per plant, pod and seed setting performance and their relationships to seed yield in common bean (*Phaseolus vulgaris* L.).

Adewale *et al.* (2010) evaluated eleven cowpea genotypes in which genotypes differ significantly ($p \leq 0.05$) in grain yield, pods/plant and dry fodder yield. Days to 50% flowering, days to maturity, 100 seed weight and pod yield were significantly ($p \leq 0.05$) influenced by the effect of genotype, year and their interactions.

2.5. Biochemical parameters

2.5.1. Chlorophyll content

As Bently Glass (1961) has to aptly stated, “Life is a photochemical phenomenon.” The chemical compounds most important in this conversion of light energy to chemical energy are the pigments that exist within the chloroplast/ chromatophores of plants. The chlorophylls, the green pigment of the chloroplast, are the most important photosynthetic plant pigment, and today at least seven types may be distinguished. Amongst these, chl ‘a’ and ‘b’ covers majority of the portion of chloroplast.

Price and Hedley (1980) determined activities of PEP carboxylase and RuDP carboxylase which correlated with chlorophyll concentration, and yellow podded types had considerably less activity than green types.

Grover and Sinha (1985) concluded that, RuBP carboxylase activity and protein decreased predominantly at the later stage of pod growth, which was mainly constituted by higher seed growth. Loss of chlorophyll was also higher at later stages of pod growth in chick pea.

2.5.2 Biochemical status of cowpea

Cowpeas are an important source of protein in developing countries, especially where they are eaten in a variety of ways (Dovlo *et al.*, 1976). A number of studies have been directed toward improving traditional cowpea products and processes for making them (Adeniji and Potter, 1980), including a major effort in this department (McWatters, 1983; McWatters and Chhinnan, 1985). Likewise, research has been applied to developing new food ingredients and products made from cowpeas and other starchy legumes (Zamora and Fields, 1979; Phillips, 1982; Sosulski *et al.*, 1982). Extrusion cooking is one of the most versatile and efficient techniques for producing ingredients and novel foods (Harper,

1981), although its application to starchy legumes has been limited. Several authors have studied the effects of extrusion on either nutritive quality (Elias *et al.*, 1976; Jorge Jao *et al.*, 1980) or on texture (Jeunink and Cheftel, 1979) of grain legumes including cowpea. However, with few exceptions (Pham and del Rosario, 1984a, b), studies on both textural and nutritional properties of the same products have not been presented.

Cowpeas are also processed into paste for the preparation of various traditional foods, such as Akara (fried cowpea paste and Moinmoin, steamed cowpea paste) (Henshaw *et al.*, 2000). Attempts to expand utilization of cowpea include investigation on processing into flour (McWatters, 1983; McWatters, 1990; Henshaw and Lawal, 1993; Henshaw *et al.*, 1996) and investigation into fungal fermentation of cowpeas (Uzochukwu *et al.*, 1999). Cowpea (*Vigna unguiculata*) is an important source of plant protein crop. Cowpea is starch-protein seeds offering a wider pattern of utilization than any other legume (Henshaw, 2000).

Bressani (1985) stated that, cowpea [*Vigna unguiculata* (L.) Walp.], is the most important source of vegetable protein in rural and urban diets across West and Central Africa and in parts of East and Southern Africa (Singh *et al.*, 1997).

The crude protein content ranges from 22 to 30% in the grain and leaves on a dry weight basis (Omueti and Singh, 1987; Nielsen *et al.*, 1997). Cowpea enhances the quality by the synergistic effect of high protein and high lysine from cowpea and high methionine and high energy from the starchy food (Singh *et al.*, 2003). The proportions of chemical components such as carbohydrate and protein influence seed cooking time (Henshaw, 2000; Henshaw and Sanni, 1995; Henshaw *et al.*, 2003).

Del Rosario *et al.* (1981) reported protein content cowpea cultivars which varied from 19.96 to 24.4 per cent.

Aravindhana and Vijendra Das (1996) reported that, in cowpea the crude protein content, the line CS-55 recorded the maximum (23.6 %) and among the testers CO-5 recorded the maximum (20 %). Among the crosses CS-55 x CO-4, CS-55 x CO-5 and IFC-901 x C-152 recorded 24.6, 31.5 and 24.2 per cent of the crude protein content respectively.

Milford *et al.* (1999) demonstrated that, the protein accumulation depended on the remobilization of nitrogen from other plant organs, primarily the leaves and pod walls.

Naik *et al.* (1990) stated that the protein content was negatively correlated with plant height and days taken to flower initiation and positively correlated with pod length and seed number and had highly positive association with seed yield and pod number.

Kachare (2005) observed considerable genetic variations for the contents of protein, nonprotein nitrogen, limiting amino acids and polyphenols. The globulins contributed about 50% of the total seed proteins. A significant proportion of proteins of high protein cultivars were found to be insoluble.

Rivas-Vega *et al.* (2006) studied the nutritional value of whole raw cowpea (WRC), dehulled (DC), cooked (CC), germinated (GC) and extruded (EXC). The crude protein content of WRC (26.1%) increased after germination (29.5%). Carbohydrates ranged from 69.4% to 85.9%. The trypsin inhibitor activity of WRC meal was low (7.52 U/mg dry matter), and was reduced or eliminated by cooking and extrusion.

Ajeigbe *et al.* (2008) showed the variations for protein (21.3-26.9%), carbohydrate (63.37-69.56%), fat (1.2-1.80%), crude fibre (0.43-1.03%), and tannin (0.87-1.51 mg/g) content also in water binding capacity (91.77-108.35%) and gelatinization temperature (79.13-84.83oC) among cowpea varieties.

Henshaw (2008) showed significant variation in physical characteristics and proximate composition in twenty-eight varieties of cowpea seeds. Ash content ranged between 3-4%, crude protein, crude fat, moisture and total carbohydrate contents had range values of 20-27, 0.6-1, 9-12 and 57 –62%, respectively.

Sebetha (2010) studied yields and protein content of two cowpea varieties. The protein content of green cowpea pods obtained from Pan 311 cowpea variety ranged from 18.8 to 25.1% while that of Red Caloona varied between 17.9 and 20.7%.

3. MATERIAL AND METHODS

The present investigation entitled “Pod Ontogeny in Cowpea [*Vigna unguiculata* (L.) Walp]” was undertaken under field condition at Pulses Improvement Project, Mahatma Phule Krishi Vidyapeeth, Rahuri, Dist. Ahmednagar during *Kharif* season of 2009 and 2010. The details of materials and methods adopted during the present investigation are given in this chapter.

3.1. Crop and variety

The experimental material comprised five genotypes of cowpea [*Vigna unguiculata* (L.)Walp.]. The pure seeds were obtained from the Officer In-charge, Pulses and Oil-seed Research Training Centre (PORTC), Pandharpur, Dist. Solapur during *kharif* 2009 (Table 1).

Table 1. The salient features of the cowpea genotypes

SN	Genotypes	Salient features
1	VCM 8	Medium cream white colour, dwarf, determinate, bushy, short duration (65-70 days).
2	Konkan Safed	Bold seed size with milky white colour, indeterminate, medium duration (85-90 days).
3	Phule Pandhari	Medium seed size with red colour, Semi-determinate, medium duration (75-80 days).
4	C 152	Medium seed size with red seed colour, indeterminate, maturity period 80 to 90 days.
5	GC 3	White seeded, Semi-determinate, flappy pods, maturity period 70-75 days.

3.2: Experimental site

Experiments were conducted at Pulses Improvement Project, MPKV, Rahuri, Dist. Ahmednagar during *Kharif* 2009 and *Kharif* 2010. The soil of experimental field was medium black with good water holding capacity and pH ranging from 7.0 to 7.5.

3.3: Climate and weather condition

Geographically, Pulses Improvement Project is situated at latitude between 19°47' and 19°57' North and longitude between

74°82' and 74°9' East. The altitude is 532 m above the mean sea levels. This tract is on the eastern side of western ghat and falls under rain shadow area.

Climatically, the area falls in semi arid tropics with annual rainfall ranging between 307 and 619 mm, the average being 520 mm which is erratic and unevenly distributed in 15 to 45 rainy days in different years. Out of the total annual rainfall, above 80% is received from South West monsoon from June to September.

In general, the seasons were fairly good during the crop growth period. The total rainfall (mm) and rainy days, average maximum and minimum temperatures (°C), humidity (%), wind velocity (km/hr), sunshine (hrs) and evaporation (mm) are given in Table 2.

3.4. Cultivation and crop management

3.4.1. Preparation of land

The soil of experimental field was medium black with 7.0 to 7.5 pH range and fairly well leveled with good drainage. One deep ploughing and two harrowings were given before sowing. The stubbles of previous crop were removed and field was brought to fine tilth before sowing. The F. Y. M. @ 5 t/ha and recommended dose (R. D.) of 25 kg N/ha and 50 kg P₂O₅ /ha was applied at the time of sowing in the form of urea and single super phosphate, respectively.

3.4.2. Experimental Design and Treatment Details

Seasons : *Kharif* 2009 and 2010

Treatments/genotypes: Five

Experimental Design : Randomized Block Design

Replications : four.

Plot Size : 4.00 x 2.40 m² (Gross), 3.60 x 1.80 m² (Net)

Spacing : 30 x 10 cm.

Irrigations : As and when required.

Table 2: Meteorological data during the year 2009-10 & 2010-2011 at Central Campus, MPKV, Rahuri.

M W	Date	Rain- fall (mm)	Rainy -days	Temp. (°C)		Humidity (%)		Wind velocity (km/hr)	Sun- shine (hrs)	Evapo ration (mm)
				Max	Min	Mor- ning	Eve- ning			
Kharif 2009										
26	25/6 -1/7	-	-	33.9	23.2	72.7	52.3	4.4	6.9	8.6
27	2/7 -8/7	43.8	2	32.4	23.5	79.4	52.6	4.9	2.4	--
28	9/7 -15/7	3.2	1	30.4	23.2	76.7	64.9	6.2	3.0	5.0
29	16/7 -22/7	0.2	-	30.0	23.3	80.0	69.0	8.4	0.4	3.6
30	23/7 -29/7	-	-	29.1	22.9	78.0	61.0	10.3	2.2	5.3
31	30/7 -5/8	-	-	30.1	22.9	74.8	56.8	5.1	--	4.2
32	6/8 -12/8	-	-	31.3	22.5	77.2	56.1	4.8	--	3.8
33	13/8 -19/8	16.8	2	32.1	21.8	77.0	50.0	1.4	3.5	3.7
34	20/8-26/8	11.8	4	30.8	21.5	90.0	62.9	0.4	3.0	2.5
35	27/8-2/9	7	1	30.1	22.1	83.1	66.9	2.3	3.7	3.2
36	3/9-9/9	29.8	4	30.0	22.0	85.3	69.4	1.1	2.4	2.6
37	10/9-16/9	42.0	2	31.9	21.4	77.3	60.7	0.7	5.3	3.9
38	17/9-23/9	-	-	33.4	21.3	77.4	47.9	0.9	7.7	5.3
39	24/9-30/9	-	-	34.4	22.4	79.6	39.7	1.3	7.8	5.5
Total/ Mean		154.6	16	31.4	22.4	79.2	57.9	3.7	4.0	4.4
Kharif 2010										
26	25/6 -1/7	15.6	4	34.7	23.7	79.7	53.6	3.5	5.8	10.6
27	2/7 -8/7	41.8	2	30.6	22.7	83.3	66.0	5.5	2.4	3.3
28	9/7 -15/7	-	-	31.9	23.4	78.0	58.1	8.4	3.2	5.5
29	16/7 -22/7	57.2	1	31.7	23.2	82.6	62.3	4.9	4.0	5.6
30	23/7 -29/7	5.6	1	29.4	22.5	84.0	66.3	8.5	1.5	3.9
31	30/7 -5/8	2.2	-	30.0	23.3	79.9	63.9	8.0	1.2	3.9
32	6/8 -12/8	29.8	1	30.6	21.6	76.9	53.7	5.4	4.3	4.7
33	13/8 -19/8	2.0	--	31.6	22.5	83.1	57.1	0.9	3.8	4.8
34	20/8-26/8	--	--	30.5	21.6	83.7	51.9	2.2	2.0	3.8
35	27/8-2/9	225.8	5	29.5	22.2	85.9	69.4	3.4	3.1	2.4
36	3/9-9/9	150.0	3	28.8	22.3	81.7	73.0	3.9	1.6	2.5
37	10/9-16/9	--	--	31.3	20.5	79.4	55.4	2.6	6.9	4.7
38	17/9-23/9	106.6	3	30.7	22.1	82.9	57.0	1.1	5.0	4.5
39	24/9-30/9	85.5	5	31.2	21.6	83.3	64.6	0.8	6.3	4.8
Total/ Mean		706.5	21	30.9	22.4	81.6	60.9	4.2	3.7	4.6

VCM-8 Medium creamy white seeded, dwarf, determinate, bushy, short duration (65-70 days) variety.	
	Konkan Safed Bold milky white seed, indeterminate, medium duration (85-90 days) variety.
Phule Pandhari Semi-determinate, medium red seeded, medium duration (75-80 days) variety.	
	C 152 Determinate, medium seed size, red seeded variety with a maturity of 80 to 90 days.
GC 3 Semi-determinate, semi-spreading growth, white seeded, flappy pods with maturity period of 70-75 days.	

Plate 1: Cowpea genotypes studied for pod ontogeny

Plate 1: Cowpea genotypes studied for pod ontogeny

3.4.3. Plan and Layout

N ← S				
RI				
5 GC 3	4 C 152	3 Phule Pandhari	2 Konkan Safed	1 VCM 8
RII				
4 C 152	3 Phule Pandhari	2 Konkan Safed	1 VCM 8	5 GC 3
RIII				
3 Phule Pandhari	2 Konkan Safed	1 VCM 8	5 GC 3	4 C 152
RIV				
2 Konkan Safed	1 VCM 8	5 GC 3	4 C 152	3 Phule Pandhari

3.4.4. Sowing

Sowing was done as per the schedule given in Table 3.

Table 3: The details of the experiments.

SN	Title of experiment	Sowing date	Matu- rity	Location
1	Pod Ontogeny in Cowpea [<i>Vigna unguiculata</i> (L.) Walp]	28.06. 2009	26.09. 2009	Pulses Improvement Project, MPKV, Rahuri, Dist.: Ahmednagar
2	Pod Ontogeny in Cowpea [<i>Vigna unguiculata</i> (L.) Walp]	26.06. 2010	28.09. 2010	Pulses Improvement Project, MPKV, Rahuri, Dist.: Ahmednagar

3.4.5. Inter-culturing operations

One seedling from hill was thinned 8 days after germinations and gap filling was done at the same time wherever required. One hand hoeing at 21 days after sowing and one hand weeding at 25 days after sowing was given and crop was kept free from weeds.

3.4.6. Plant protection measures

Two spraying of Bovistin + Monocrotophos at pre- and post-pod filling stages were given for the controlling the infestation of powdery mildew, pod borer and white fly.

3.5. Observations recorded

3.5.1. Pod and seed development (3 days interval from flowering)

1. Fresh and dry weight of flowers (g)
2. Fresh and dry weight of pods (g)
3. Fresh and dry weight of seeds (g)
4. Length of pods (cm)
5. Diameter of pods (mm)
6. Girth of pods (mm)
7. Length of seeds (mm)
8. Breadth of seeds (mm)
9. Pod volume (ml)
10. Seed volume (ml)

3.5.2. Phenological studies (Juvenility)

1. Days to 1st flower bud
2. Days to last flower bud
3. Days to 1st flower
4. Days to last flower
5. Days to 1st pod
6. Days to last pod
7. Days to 1st pod maturity
8. Days to last pod maturity

3.5.3. Morpho-Physiological characters (20 days interval from sowing)

1. Dry matter production and it's assimilation in component parts of plant
2. Plant height, number of branches/ plant, number of leaves/ plant and leaf area
3. Growth parameters (AGR, RGR, NAR, LAR, LAI, SLA and LAD)
4. Photosynthesis, transpiration, stomatal conductance and water use efficiency

3.5.4. Generative characters at harvesting

1. Pods/ plant (No.)
2. Seeds/ pod (No.)
3. Seeds/ plant (No.)
4. Seed yield/ plant (g)
5. Seed yield / plot (kg)
6. Seed yield (kg/ha)
7. Fodder yield (kg/plot)
8. Total biomass/ plot (kg)

9. 100 seed weight (g)

10. Harvest index (%)

3.5.5. Biochemical parameters

1. Crude protein content in seeds

2. Reducing sugars in seeds

3. Carbohydrate content in seeds

4. Starch in seeds

5. Fat content in seeds

6. Fiber content in seeds

7. Niacin content in seeds

8. Thymine content in seeds

9. *B*-carotene content in seeds

10. Chlorophyll content in pod wall

3.6. Methods

3.6.1. Pod and seed development

At the stage of 50 per cent flowering 500 flowers of uniform stage were tagged in each genotype in each replication. From the date of tagging 10 flowers/ pods were sampled at an interval of 3 days in each genotype and replications. The observations on fresh weight, dry weight, length, girth and volume etc. were recorded on each sample of flowers, pods as well as pod shell and seeds.

i. Estimate of pod filling period

Length of the reproductive period from anthesis to maturity of individual pods is the pod development period. The seed filling period (SFP) is the duration of dry matter accumulation in seeds (Egli *et al.*, 1984). The maximum pod and seed increase rate were calculated by dividing the weight gain during the linear phase of pod and seed growth by the duration of that period.

ii. Pod and seed growth rate

Pod dry weight increase was judged linearly during days 3-6, 3-9, 3-12, 3-15, 3-18, 3-21 and 3-24 days after flowering for pod growth rate, however, seed dry weight increase was judged during days 6-9, 6-12, 6-15, 6-18, 6-21 and 6-24 days after flowering for seed growth rate (Wien and Ackah, 1978). Relative growth rate of pod and seeds were calculated by progressive increase of dry weights in a given period of time (Radford, 1967).

iii. Actual pod development period (APDP)

The actual pod development period was recorded as period from the date of pod formation to pod maturity.

iv. Effective pod development period (EPDP)

It was calculated by the final dry weight divided by the rate of increased dry weight /day in the linear phase of pod growth (Daynard, 1971). It was expressed as:

$$\text{Effective pod growth period (days)} = \frac{\text{Final pod dry weight}}{\text{Pod dry weight increase per day}}$$

v. Actual seed growth period (ASGP)

Actual seed growth period is the period from seed formation to seed maturity.

vi. Effective seed growth period (ESGP)

The effective seed growth period was expressed as final dry weight of seeds per pod divided by the rate of increase in dry weight of seed per day in linear phase.

$$\text{Effective seed growth period (days)} = \frac{\text{Final dry weight of seeds per pod}}{\text{Seed dry weight increase per day}}$$

vii. Lag period

$$\text{Lag period} = \text{APDP} - \text{EPDP}$$

vii. Polynomial functions

In a polynomial function the dependent variable is expressed as a function of two or more terms. The title is particularly applied to expressions involving sum of independent terms which are each different powers of the same primary variables (Hunt, 1982).

If we have a variate X which is dependent, then the simplest case of regression of Y on X is given by a linear equation $Y = a + bX$. Here Y is the value one which expects to obtain corresponding to any given X on the basis of observed linear relation in this equation. The two components 'a' and 'b' are so chosen that the quantity $\sum(Y - Y')^2$ is minimum. This is known as the principle of least squares

(Panse and Sukhatme, 1985). In this quantity Y stands for the observed value of the dependent variate. Y for the value obtained by substituting in the equation the corresponding X value. This quantity, therefore, represents the sum of squares of deviations of observed value of Y from those predicted from the regression equation and forms the residual variation after the regression line is thus the relation between Y and X which minimizes the residual variation in Y . The calculation of 'a' and 'b' can be done by the following formulae:

$$a = Y - bX$$

$$b = \frac{\sum(Y-Y^-)(X-X^-)}{\sum(X-X^-)^2}$$

The quantity $\sum(Y-Y^-)(X-X^-)$ which is obviously sum of products of deviations X and Y from respective means can also be expressed as; $\sum(Y-Y^-)(X-X^-) = \sum Y(X-X^-) = \sum X(Y-Y^-)$.

This relation of Y to X frequently may be better represented by lines of higher orders.

The equation may be:

Quadratic equation $Y = b_0 + b_1X + b_2X^2$

Cubic equation $Y = b_0 + b_1X + b_2X^2 + b_3X^3$

Indeed any power of X $Y = b_0 + b_1X + b_2X^2 + b_3X^3 + \dots$

The coefficient $b_0, b_1, b_2, b_3, \dots$ in the polynomial regression equation are estimated by minimizing the quantity $(Y-Y^-)^2$ representing the residual variation. This leads to the following normal equations (Amble, 1975).

$$(n) \quad b_0 + (\sum X) b_1 + (\sum X^2) b_2 + \dots = \sum Y$$

$$(\sum x) \quad b_0 + (\sum X^2) b_1 + (\sum X^3) b_2 + \dots = \sum XY$$

$$(\sum x^2) \quad b_0 + (\sum X^3) b_1 + (\sum X^4) b_2 + \dots = \sum X^2Y$$

Here we know the values of n, x and y . Hence, the calculations of these equations lead to the estimation of polynomial constants $a, b_1, b_2, b_3, \dots$ etc. The calculations can be done

more conveniently either by following a systemic procedure suggested by Amble (1975) by short cut method outlined by Little and Hills (1978) or by using orthogonal polynomials given by Fisher and Yates (1963). In the present investigation the constants of polynomial were worked out on a computer in multiple regressions on the basis of polynomial fitted design.

A Co-efficient of determination is given by the estimate of R^2 which is a ratio of sum of squares due to regression to the total sum of squares. The central objective in fitting polynomial is to discover the simplest polynomial which accounts for a specified high proportion of the total variation in Y.

3.6.2. Phenological studies (Juvenility)

The growth and phenology of the crop was critically monitored on every day on randomly selected plants of every genotype. The total maturity periods of individual pod and maturity period of crops are calculated by using following formula.

Total maturity period	=	Days to first flower + bud	Bud to flower + anthesis	Duration for flowering to pod set	Pod set to Maturity
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Maturity period	=	First bud appearance (d) + Bud to first flower (d) + First flower to first pod set (d) + First pod set to first maturity (d) + Staggered flowering period (d) - Period of difference between last flower to first pod (d)
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3.6.3. Crop physiology

i. Dry matter partitioning and it's distribution in component parts of plants

For dry matter studies five plants, other than observational plants were randomly selected at 20 days interval from each net plot, which were also used for estimation of leaf area. The selected plants were uprooted from the soil with the presence of roots for taking required observations. These plants were further, separated

into root, stem, leaves, flowers and pods. These were properly labeled and dried in hot air oven at 80°C for next 48 hrs till the constant weight was obtained. When plant parts were completely dried the weights were recorded separately for each plant part i.e. stems, leaves, flowers and roots etc. Finally these weights were calculated on per plant basis for studying the dry matter accumulation in different plant parts. The dry weights of leaves, pods, stems, roots and flowers were added together to obtain the total dry weight per plant.

ii. Leaf area

The leaf area was measured by using automatic leaf area meter. The leaves were separated at the time of sampling, three leaves each from top, middle and basal portion were taken for taking the individual leaf area. The total leaf area was estimated on unit leaf area basis. The total dry matter production (TDM) and leaf area/plant (LA) is estimated as below;

$$\text{TDM} = \text{Dry matter (Root + stem + leaves + pods)}$$

$$\text{LA} = \text{Unit leaf area} \times \text{Total number of leaves}$$

iii. Growth parameters

The data on leaf area and dry weights of plant with their component parts of plant recorded at different intervals were employed to compute various physiological growth functions. The leaf area at desired stage was measured by leaf area meter in mm².

Absolute growth rate (AGR):

The absolute growth rate (AGR) is a plain and simple measure of rate of increase in weight. AGR was calculated by formula given by Briggs *et al.* (1920) and expressed as g/day/plant.

$$\text{AGR} = \frac{W_2 - W_1}{T_2 - T_1} \quad \text{Where, } W_2 \text{ and } W_1 \text{ are dry weights per plant.}$$

$T_2 \text{ and } T_1 \text{ are time interval.}$

Relative growth rate (RGR)

The rate of incorporation of new material in the plant was measured by relative growth rate (RGR), which was mathematically calculated with following formula earlier given by Blackman (1919) and expressed in g/g/day

$$\text{RGR} = \frac{\text{Log}_e W_2 - \text{Log}_e W_1}{T_2 - T_1} \quad \text{Where, } W_2 \text{ and } W_1 \text{ are dry weights per plant}$$

$\text{and } T_2 \text{ and } T_1 \text{ are time interval.}$

Net assimilation rate (NAR)

Net assimilation rate (NAR) represents the photosynthetic efficiency of the leaves. NAR is the rate of increase in dry weight per unit time. The relationship between leaf area and dry matter accumulation was measured with help of NAR by using formula suggested by Gregory (1926) and Gardner *et al.* (1988) and is expressed as g/dm²/leaflet/day.

$$\text{NAR} = \frac{(\text{Log}_e L_2 - \text{Log}_e L_1) \times W_2 - W_1}{(L_2 - L_1) \times (T_2 - T_1)}$$

Where, W_2 and W_1 are dry weights per plant at time interval T_2 and T_1 . L_2 and L_1 are leaf area per plant at time interval T_2 and T_1 .

Leaf area ratio (LAR)

The leaf area ratio was worked out as per the formula given by Radford (1967) and was expressed as dm²/ g.

$$\text{LAR} = \frac{\text{RGR}}{\text{NAR}}$$

Leaf area index (LAI)

Leaf area index is the ratio of the total leaf area to the ground area per plant. The leaf area index therefore, worked at various stages of plant growth by using formula given by Watson (1947) and expressed in dm²/ plant.

$$\text{LAI} = \frac{\text{Leaf area per plant}}{\text{Land area per plant}}$$

Specific Leaf Area (SLA)

Specific Leaf Area (SLA) was calculated as per the formula given by Radford (1967) and it is expressed in dm²/g.

$$\text{SLA} = \frac{\text{Leaf area per plant}}{\text{Dry weight of leaves per plant}}$$

Leaf area duration (LAD)

Leaf area duration was calculated by the following formula given by Watson (1947) and Gardner *et al.* (1988) and it is expressed in days.

$$\text{LAD} = \frac{(\text{LAI}_1 + \text{LAI}_2)}{2} \times (\text{T}_2 - \text{T}_1)$$

Where, LAI₁ and LAI₂ represent the leaf area index (LAI) at time T₂ and T₁, respectively

iv. Photosynthesis, transpiration, stomatal conductance and water use efficiency

The photosynthetic rate (Pn), transpiration rate (E; mmol m⁻² s⁻¹) and stomatal conductance (g_s; μmol H₂O m⁻² s⁻¹) were measured using Infra-red Gas Analyser (IRGA; Model Portable Photosynthesis System LI 6400, LI-COR® Inc, Lincoln, Nebraska, USA). The E and G_s were measured continuously monitoring H₂O of the air entering and existing in the IRGA headspace chamber. Measurements were made at mid day, between 11:30 and 12:00 eastern day time (1400–1800 mmolm⁻² s⁻¹ PPFD), on top fully expanded third leaf blades. The flow rate of air in the sample line was adjusted to 500 μmol s⁻¹.

The water use efficiency (WUE) was calculated as the ratio of NPR to E.

$$\text{Water used efficiency (WUE)} = \frac{\text{Net photosynthetic rate (NPR)}}{E}$$

3.6.4. Morphological characters at harvesting

Plant height (cm): The plant heights of observational plants were measured in centimeters at 20 days interval from ground level upto the base of fully emerged leaf of main shoot.

Branches/ plant (No.): The number of branches on main shoot as well as auxiliary shoots of observational plants was recorded at 20 days interval.

Leaves/Plant: The number of leaves of observational plants was recorded at 20 days interval.

Leaf area/ plant: The leaf area of 3 leaves each from top, middle and basal portion of randomly selected plant was taken on automatic leaf area meter. The average of these leaves was multiplied with total number of leaves for the estimation of leaf area/ plant.

Pods/ plant (No.): The numbers of pods from observational plants were collected in three picks till full maturity and counted for pods/ plant.

Seeds/ pod (No.): Randomly five pods from each observational plant were taken for counting the number of seeds/ pod. The average of totally 25 pods was taken for seeds/ pod.

Seeds/ plant (No.): It was calculated by multiplying the number of pods per plant to that of seeds/ pod.

Seed yield/ plant (g): The total seed yield of observational plants was weighed and average was calculated by dividing the number of observational plants.

Seed yield / plot (kg): The seed yield from all the plant population saved in net plot was taken for seed yield / plot.

Total biomass/ plot (kg): The stover yield was taken and added with the seed yield for estimating the total biological yield.

100 seed weight (g): Randomly 100 seeds were counted from each treatment and weighed on top pan balance.

Harvest index (%): From the data of total biological yield at harvest and grain yield, the harvest index per plant was calculated by using formula given by Donald (1962).

$$\text{Harvest index (\%)} = \frac{\text{Grain yield}}{\text{Biological yield}} \times 100$$

3.6.5 Chemical analysis

i. Crude protein

The protein content has been determined on the basis of total nitrogen content, while the Kjeldahl method has been applied for the determination of nitrogen content (AOAC, 2000).

Materials: Ground seed material, H₂SO₄ (Concentrated and 0.1N), NaOH (33% and 0.1N), catalytic agent (a mixture of equal weight of CuSO₄ and K₂SO₄) , mixed indicator solution (40 mg methyl red and 1.5 mg methylene blue dissolved in 10 ml ethanol), Kjeldahl-apparatus, bunsenburner, conical flasks (50 ml), burets (50 ml), pipettes (25 ml, 10 ml), spatula, boiling chips or glass beads.

Procedure: Mixed 1.0 g finely grinded seed material with 10 ml of nitrogen free concentrated H₂SO₄ in a digestion flask. A spatula of mixture of CuSO₄ and K₂SO₄ added into the flask. To avoid bumping of acid, added few chips of porcelein to the mixture. Digested over a covered flame very gently until the initial foaming ceased. Increased and continued heating till the solution becomes completely clear.

After cooling the digest, transferred it quantitatively into the distillation chamber of a Kjeldahl-apparatus. Rinsed the digestion flask a couple times with distilled water and transferred it to the

distillation chamber. 40 ml of 33% NaOH added through the funnel to the digest.

Placed 25 ml 0.1N H_2SO_4 and a few drops of mixed indicator solution in a conical flask. Connected the Kjeldahl distillation apparatus in such a way that the tip of the condenser dips below the surface of the acid. Started steam distillation by boiling water in the round-bottomed flask. Upon steam distillation NaOH reacted with $(\text{NH}_4)_2\text{SO}_4$ to liberate ammonia to which it collected in H_2SO_4 . Distillation continued for 7-10 min. The conical flask taken away in which NH_3 was collected. The tip of the condenser rinsed with few ml of distilled water. Should the colour of the indicator change before the distillation is completed, add a known volume of acid into the conical flask.

Calculated the excess of acid left in the conical flask by titrating the acid against 0.1 NaOH from a burette.

After determining the volume of excess of acid, find out the volume of acid neutralized by NH_3 . Calculate nitrogen content (% in dry matter) by assuming that 1 ml of 0.1N H_2SO_4 is equivalent to 1.4 mg of nitrogen.

The crude protein was estimated by multiplying the total nitrogen content by 6.25 factor as described by Jones (1941).

ii. Reducing Sugars

The reducing sugars estimated by Nelson-Somogyi Method as per the procedure described by Somogyi (1952).

Materials : a) Alkaline Copper Tartrate

(i) Dissolved 2.5 g anhydrous sodium carbonate, 2 g sodium bicarbonate, 2.5 g potassium sodium tartrate and 20 g anhydrous sodium sulphate in 80 ml water and made 100 ml volume.

(ii) Dissolved 15 g copper sulphate in a small volume of distilled water. Added one drop of sulphuric acid and made 100 ml volume.

Mixed 4 ml of B and 96 ml of solution A before use.

b) *Arsenomolybdate reagent:* Dissolved 2.5 g ammonium molybdate in 45 ml water. Added 2.5 ml sulphuric acid and mixed well. Then added 0.3 g disodium hydrogen arsenate dissolved in 25 ml water. Mixed well and incubated at 37°C for 24-48 hrs.

c) *Stad. glucose solution:* *Stock:* 100 mg in 100 ml distilled water.

d) *Working standard:* 10 ml of stock diluted to 100 ml with distilled water [100 µg/ml].

Procedure

1. Weighed 100 mg of the sample and extracted the sugars with hot 80% ethanol twice (5 ml each time).
2. Collected the supernatant and evaporated it by keeping it on a water bath at 80°C.
3. Added 10 ml water and dissolved the sugars.
4. Taken aliquots of 0.1 ml to separate test tubes.
5. Taken 0.2, 0.4, 0.6, 0.8 and 1 ml of the working standard solution into a series of test tubes.
6. The volume in both sample and standard tubes made to 2 ml with distilled water.
7. Taken 2 ml distilled water in a separate tube to set a blank.
8. Added 1 ml of alkaline copper tartrate reagent to each tube.
9. Placed tubes in boiling water for 10 minutes.
10. The tubes were cooled and added 1 ml of arsenomolybolic acid reagent to all the tubes.
11. Made the volume in each tube to 10 ml with water.
12. Absorbance of blue colour was recorded at 620 nm after 10 min.
13. From the graph drawn, calculated the amount of reducing sugars present in the sample.

iii. Total carbohydrate

The total carbohydrate estimated by anthrone reagent method as per the procedure described by Hodge and Hofreiter (1962).

Materials

2.5 N HCl, *Anthrone reagent:* Dissolve 200 mg anthrone in 100 ml of ice-cold 95% H₂SO₄. Prepare fresh before use, *Standard*

glucose: Stock—Dissolve 100 mg in 100 ml water. Working standard—10 ml of stock diluted to 100 ml with distilled water. Store refrigerated after adding a few drops of toluene.

Procedure

1. Weighed 100 mg of the sample into a boiling tube.
2. Hydrolyzed by keeping it in a boiling water bath for three hours with 5 ml of 2.5 N HCl and cooled to room temperature.
3. Neutralized it with solid sodium carbonate until the effervescence ceases.
4. Made volume to 100 ml and centrifuged.
5. Collected the supernatant and taken 0.5 aliquot for analysis.
6. Prepared the standards by taking 0, 0.2, 0.4, 0.6, 0.8 and 1 ml of the working standard. '0' served as blank.
7. Made the volume to 1 ml in all the tubes including the sample tubes by adding distilled water.
8. Then added 4 ml of anthrone reagent.
9. Placed in a boiling water bath for 8-10 minutes.
10. Cooled rapidly and absorbance of green to dark green colour was recorded at 630 nm.
11. Drawn a standard graph by plotting concentration of the standard on the X-axis *versus* absorbance on the Y-axis.
12. From the graph calculated the amount of carbohydrate present in the sample tube.

iv. Starch

The starch estimated by anthrone reagent method as per the procedure described by Hodge and Hofreiter (1962).

Materials

Anthrone: Dissolve 200 mg anthrone in 100 ml of ice-cold 95% sulphuric acid, 80% ethanol, 52% perchloric acid, *Standard glucose*: Stock-100 mg in 100 ml water. Working standard-10 ml of stock diluted to 100 ml with water.

Procedure

1. Homogenized 0.1–0.5 g of the sample in hot 80% ethanol to remove sugars. Centrifuged and retained the residue. The residues

were washed repeatedly with hot 80% ethanol till the washings do not give colour with anthrone reagent. The residue was well dried over water bath. 2. To the residue added 5.0 ml of water and 6.5 ml of 52% perchloric acid. 3. Extracted it at 0°C for 20 min. Centrifuged and kept the supernatant. 4. Repeated the extraction using fresh perchloric acid. Centrifuged and kept the supernatants and made volume to 100 ml. 5. Taken 0.1 ml of the supernatant and made volume to 1 ml with water. 6. Prepared the standards by taking 0.2, 0.4, 0.6, 0.8 and 1 ml of the working standard and made the volume to 1 ml in each tube with water. 7. Added 4 ml of anthrone reagent to each tube. 8. Heated for eight minutes in a boiling water bath. 9. Cooled rapidly and absorbance of green to dark green colour was recorded at 630 nm.

v. Estimation of fat, fiber, niacin, thymine and B-carotene

The fat, fiber and vitamins from cowpea seed samples were estimated on NIR spectrometer (ZEUTEC Make), is a dual-beam near infrared spectrometer. In the NIR spectrometer, the sample is exposed near infrared light of specific wavelengths, selected from up to 19 high precision interference filters. The light penetrated the sample, interacted with sample molecules and is partly absorbed and partly diffusely reflected. The reflected light is measured by a lead sulfide (PbS) detector mounted in a gold coated integrating sphere located above the sample.

The amount of light absorbed by the sample at different wavelengths is directly related to the concentration of chemical functional groups, such as C-H, O-H and N-H. As these concentrations are in turn related to the concentrations of the properties of interest, e.g. fat, protein or moisture, property values can be determined.

Before the instrument used to analyze samples, representative set of similar samples of the product calibrated by using their known reference values. These values must have been obtained by using standard laboratory methods of high accuracy. In a calibration, a correlation between the NIR absorbance values at the different wavelengths and the sample composition is established, and calibration constants are calculated for each wavelength.

Analysis cycle

During a measurement, the filter wheel successively rotates each filter selected for the analysis into the light beam. The number of required filters depends on the reflectance characteristics of the properties to be measured.

At each filter position, the measurement time is equally divided into a sample, a reference and second sample signal period. To determine the true sample reflectance at the wavelength of the current filter, the average of the two sample signals is taken. This procedure reduces the effects of drift and noise on the calculated result.

The following sequence is carried out during an analysis cycle: 1. Upon entry into an analysis cycle, the filter wheel is at the opaque blank position, and the mirror is in the sample position. 2. The filter wheel is rotated to the first filter selected for the analysis. 3. The light reflected by the sample is measured ($I_{1 \text{ sample}}$). 4. The mirror moves to the reference position. 5. The light reflected by the sphere will be measured as reference reading ($I_{\text{Reference}}$). 6. The mirror moves back to the sample position. 7. The light reflected by the sample is measured again ($I_{2 \text{ sample}}$). 8. The filter wheel moves to the next filter position.

Steps 3 to 8 are repeated for each filter to be used in the analysis. While the filter wheel is moving to the next filter position,

the reflectance R_i at the i^{th} filter position just measured is calculated as follows;

If specified for the product, these reflectance values can be undergoing an absorbance transformation and/ or a whole grain or 2 wavelength normalization.

The following equation is used to finally relate the pretreated values Y_i at the different wavelengths to the composition of the sample and to actually calculate the property values.

$$P_j = b_j + m_j \sum_{i=1}^{19} F_i^j \times Y_i$$

Where, P_j = Property value for property j ($j = 1, 2, 3, \dots, 15$)

b_j = Intercept of regression line for property j (derived from calibration)

m_j = Slope (screw) for property j (derived from calibration)

F_i^j = Regression coefficient for filter i and property j (derived from calibration)

Y_i = Reflectance value after transformation for filter i ($i = 1, 2, 3, \dots, 19$)

b_j , m_j and F_i^j are derived from calibration calculations.

vi. Chlorophyll content in pod walls.

The chlorophyll content in pod wall estimated as per the procedure described by Glass (1961).

Material required:

1. Acetone, BDH /Analar, 2. Whatman No.1,
3. Funnel stand, 4. Mortar and pestle,
5. Volumetric flasks (25 ml), 6. Spectronic-20/ spectrophotometer.

Procedure: Eighty percent acetone is prepared. 250 mg of fresh pod wall is accurately weighed on electronic monopan balance and transferred to mortar and pestle for grinding. 10 ml of 80% acetone is added in it and walls are thoroughly macerated. A homogeneous pestle is made. Chlorophyll extract is poured in a funnel having whatman paper No. 1 and collected in volumetric flask. Every care

is taken to collect all the extract from mortar. The green extract is gradually obtained by adding 5 ml of acetone (80%) every time. Three to four washings are given and extraction continued until leachate becomes colourless. Volume should not exceeded 25 ml eventually. Made the volume to 25 ml with 80% acetone. Since the extract is subjected to photo-oxidation, it is kept away from direct sunlight and stored in refrigerator. The optical density of the chlorophyll extract is recorded on spectronic-20 using 645, 652 and 663 nm wavelength.

Following formulae are used for calculation of Chlorophyll a, b and total chlorophyll (mg/g).

$$\text{Chlorophyll 'a'} = 12.7 (D.663) - 2.69 (D.645) \times V / 1000 \times W$$

$$\text{Chlorophyll 'b'} = 22.9 (D.645) - 4.68 (D.663) \times V / 1000 \times W$$

$$\text{Total chlorophyll} = \frac{D.652 \times 1000}{34.5} \times \frac{V}{1000 \times W}$$

Where, D= Optical density.

V= Final volume of 80% acetone (25 ml).

W= Weight of leaf sample taken (0.25 g).

3.7. Statistical analysis

i. Estimation of mean and range

The arithmetic mean values for each of the characters studied were calculated by dividing the total of observations by the corresponding number of observations as given below;

$$\text{Mean (X)} = \frac{\text{Total of the observations}}{\text{Number of observations}}$$

The lowest and highest values from mean of each character were recorded as range.

ii. Analysis of the design of the experiment

The data available on individual characters were subjected to the method of analysis of variance, commonly applicable to the Randomized block (Panse and Sukhatme, 1985).

ANOVA TABLE

Source	Degrees of freedom	Sum of square	Mean sum of square	F calculated
Replication	(r-1)	$\sum r_i^2$	$\sum r_i^2 / (r-1)$	RMSS/ ErMSS
Treatment	(t-1)	$\sum t_i^2$	$\sum t_i^2 / (t-1)$	TMSS/ ErMSS
Error	(r-1) x (t-1)	$\sum x_i^2$	$\sum x_i^2 / (r-1) \times (t-1)$	

Where, r = Number of replications,
t = Number of treatments.

The treatment mean square (TMSS) were tested against error mean square (ErMSS) by 'F' test for N1 = (t-1) and N2 (r-1) x (t-1) degrees of freedom.

iii. Estimation of standard error and critical difference

The standard error of mean was calculated as;

$$\text{SE of mean (SEM)} = \frac{\sqrt{6^2 e}}{r}$$

The critical difference (CD) between any two means was calculated as;

$$\text{CD} = 't' \text{ at error d.f.} \times \text{SEM} \times \sqrt{2}$$

iv. The critical standard deviation and coefficient of variation

The standard deviation was calculated by using the formula;

$$6 = \frac{\sqrt{\sum d^2}}{n} \quad d = (X - \bar{X}) = \text{Deviation between mean and value.}$$

N = Number of observations.

$$\text{CV} = \frac{6}{\bar{X}} \quad \text{Where, } 6 = \text{Standard deviation.}$$

X = Mean of the character.

3.8. Morphological characters

Observations were recorded for seedling, plant and seed characters and categorized into different groups as given below;

Sr. No.	Characteristics	Category	Stage
1	Pigmentation	a) Green b)Purple	Seedling
2	Leaflet colouration	a) Green, b)Purple	Seedling
3	Early plant vigour	a) Very good, b) Good, c)Poor	Seedling
4	Plant growth habit	a) Erect b) Semi-spreading c) spreading	50% flowering
5	Branching habit	a) Less, b)Medium, c) Profuse	50% flowering
6	Stem colour	a) Green, b) Purple	50% flowering
7	Foliage colour	a) Green, b) Dark green	50% flowering
8	Leaflet margin	a) Medium b)High	50% flowering
9	Flower colour	a) White b)Violet c) Pinkish	50% flowering
10	Pod size	a) Small b)Medium c) Bold	Maturity
11	Seed size	a) Small b)Medium b) Bold	At ripe seed
12	Seed shape	a) Oval b)Angular c) Pea shape	At ripe seed
13	Seed surface texture	a) Smooth b) Wrinkled	At ripe seed
14	Seed colour	a) White b) Red c) Dark red	At ripe seed
15	Seed type	a) Whitish b)Reddish	At ripe seed

4. EXPERIMENTAL RESULTS

The ontogenic development with reference to changes in fresh and dry weights of flowers/ seeds, development of pod wall and ontogenic growth of seeds inside the pod are presented in this chapter for overall phenology and growth of crop. The varietal variations from seed and pod development and overall generalization on the pattern of pod development are presented on the background of growth characters.

In the ontogeny of crop, the initial phase is always characterized by emergence of the seedlings, formation of branches, production of leaves and after attaining the vegetative growth, the plant enters into reproductive phase.

Reproductive phase commence with the appearance of buds, opening of flowers, setting of pods, development of pods in terms of length, breadth, girth and volume. Thus, the pod shell is initially developed and then at the same stage the setting of grain occurs which is followed by filling of the seeds. The seed develops by length, breadth, girth and volume and ultimate product is formed by deposition of photosynthates in the reproductive sink.

Thus, this whole process is a result of nebulous metabolic activities. A clear understanding of all this process, especially pod development and seed filling is essential in designing plant/ crop architecture for high productivity.

In this chapter results on pod and seed ontogeny and other related aspects of growth in five cowpea genotypes are presented.

4.1. Characters of pod development

In cowpea, the overall yield depends upon number of pods and size of seed. It is well known that the size and number of pods are the genetically determined characters. Further, height of plant, phenological duration/ periods of different phases in post anthesis

phases and overall length of anthesis to maturity, pods bearing branches etc. contributes for final yields. The rates of development of pod, pod wall and the seed inside the pods have direct bearing on overall crop performance.

4.1.1. Fresh and dry weight of flower

The data on fresh and dry weight of flower is presented in Table 4. The treatment differences were statistically significant for both the characters.

Flower is first site from where the development of pods initiate after fertilization. According to the genotype, in cowpea, there is a variation in size, weight and colour of flower. In the present investigations, fresh weight of flower ranged between 2.55 (VCM 8) and 3.44 g (GC 3) per flower. All the genotypes were significantly superior for fresh flower weight over VCM 8. The highest (0.31 g) and lowest (0.24 g) dry weight of flower was recorded by the genotypes Konkan Safed and VCM 8, respectively.

Table 4. Fresh and dry flower weight of cowpea genotypes

Genotypes	Fresh weight of flower (g)	Dry weight of flower (g)
VCM 8	2.55	0.24
Konkan Safed	3.36	0.31
Phule Pandhari	3.19	0.28
C 152	3.23	0.28
GC 3	3.44	0.30
Mean	3.15	0.28
SE _±	0.188	0.011
CD at 5%	0.581	0.035

4.1.2. Pod length

The constants of regression coefficient of the polynomial fitted for periodical changes in pod length of cowpea genotypes are presented in Table 5 and 6. It revealed that, differences among the

genotypes for pod length were statistically significant at various stages of growth.

The genotype Konkan Safed (5.75 cm) recorded highest pod length at 3 DAF followed by C 152 (5.19 cm) and GC 3 (4.79 cm). However, at 6 DAF, GC 3 (10.67 cm) and Konkan Safed (9.27 cm) maintained highest pod length. 9 DAF onwards, C 152 and VCM 8 being highest and lowest pod length at 9th (15.38 & 12.11 cm), 12th (16.06 & 12.73 cm), 15th (16.15 & 11.91 cm), 18th (15.11 & 11.90 cm), 21st (15.00 & 11.88 cm) and 24th DAF (15.00 & 11.88 cm), respectively. The rate of increase for pod length was higher in GC 3 (1.96 cm/day) and VCM 8 (1.60 cm/day) between 3 and 6 DAF, however it was higher in C 152 (2.46 cm/day) and Phule Pandhari (1.26 cm/day) at 6-9 DAF (Appendix-I). Konkan Safed (0.66 cm/day) and Phule Pandhari (0.50 cm/day) had higher rate for increasing pod length at 9-12 DAF. After 15 DAF, the rate was minimized due losses in moisture content from the pods towards maturity.

Table 5. Periodical changes in pod length of cowpea genotypes

Genotype \ DAF	Pod length (cm)							
	3	6	9	12	15	18	21	24
VCM 8	3.70	8.49	12.11	12.73	11.91	11.90	11.88	11.88
Konkan Safed	5.75	9.27	12.97	14.96	15.38	14.96	14.39	14.39
Phule Pandhari	4.26	8.81	12.59	14.10	14.32	13.97	13.94	13.94
C 152	5.19	8.00	15.38	16.06	16.15	15.11	15.00	15.00
GC 3	4.80	10.67	13.67	15.13	15.16	14.85	14.44	14.44
Mean	4.74	9.05	13.34	14.60	14.58	14.16	13.93	13.93
SE _±	0.34	0.38	0.35	0.18	0.20	0.30	0.22	0.22
CD at 5%	1.04	1.18	1.08	0.54	0.63	0.93	0.68	0.68

The general form of the equation for pod length was Y (pod length) = $b_0 - b_1X + b_2X^2 - b_3X^3$ except for Phule Pandhari. A variable picture was noticed as regards to the values of b_0 and b_1 . The

genotype Phule Pandhari has extremely negative value of b_0 but had maximum value of b_1 which suggested that there was a rapid increase in pod length during the course of growth from the extremely small value at 0 times i.e. at anthesis. In contrast, VCM 8 had higher magnitude of b_0 and low magnitude of b_1 which suggested that at the time of setting of pod itself pod length was high. The coefficient of determination (R^2) was non significant for all the genotypes indicated that the cubic polynomial was not appropriately fit for pod length in all the genotypes.

Table 6. Values of regression coefficient of polynomials fitted for pod length in cowpea genotypes from the stage of flowering

Genotypes	Values of regression co-efficient				R^2
	b_0	b_1	b_2	b_3	
VCM 8	149.4461 (89.83)	-68.7289 (40.86)	9.2445 (5.36)	-0.3695 (0.21)	0.7021
Konkan Safed	65.7289 (111.90)	-21.5351 (35.79)	2.2505 (3.55)	-0.0687 (0.11)	0.6502
Phule Pandhari	-6.9989 (78.36)	4.2506 (31.12)	-0.5591 (3.63)	0.0271 (0.13)	0.6778
C 152	60.2325 (62.83)	-22.9642 (20.45)	2.7999 (2.06)	-0.0968 (0.07)	0.7206
GC 3	105.5364 (130.65)	-37.3303 (46.92)	3.9102 (4.91)	-0.1211 (0.16)	0.6268

Figures in parentheses indicate SE values of variates.

4.1.3. Pod girth

The periodical changes and constants of polynomials in pod girth of cowpea genotypes are presented in Table 7 and 8. The differences among the genotypes for pod length were statistically significant at different stages of growth except at 9 DAF.

The genotype Konkan Safed (6.52 mm) recorded highest pod girth at 3 DAF followed by VCM 8 (5.99 mm) and Phule Pandhari (5.78 mm). However, at 6 DAF, GC 3 (12.84 mm) and VCM 8 (10.50

mm) were found to be superior for higher pod girth. At 9 DAF, Phule Pandhari (18.62 mm) and VCM 8 (18.39 mm) maintained higher pod girth. The genotype C 152 maintained highest pod girth at 12th (20.99 mm), 15th (21.19 mm), 21st (20.55 mm) and 24th DAF (20.54 mm), respectively. However, at 18th DAF, Konkan Safed (20.75 mm) found to be superior for pod girth. The genotype VCM 8 at 12th (19.51 cm), 15th (18.55 cm) and 18th DAF (17.66 cm) and GC 3 at 21st (17.60 cm) and 24th DAF (17.59 cm) showed minimum pod girth. The rate of increase for pod girth was higher in GC 3 (2.75 mm/day) and VCM 8 (1.50 mm/day) between 3 and 6 DAF, however, it was higher in C 152 (2.87 mm/day) and Phule Pandhari (2.80 mm/day) at 6 to 9 DAF (Appendix-I). Konkan Safed maintained higher rate for increasing pod girth at 9 to 12 (0.99 mm/day) and 12 to 15 DAF (0.38 mm/day). After 15 DAF, the rate was minimized due losses in moisture content from the pods towards maturity.

Table 7. Periodical changes in pod girth of cowpea genotypes

DAF Genotype	Pod girth (mm)							
	3	6	9	12	15	18	21	24
VCM 8	5.99	10.50	18.39	19.51	18.55	17.66	17.67	17.65
Konkan Safed	6.52	10.03	16.96	19.93	21.06	20.75	18.97	18.96
Phule Pandhari	5.78	10.21	18.62	19.51	20.12	19.71	19.66	19.65
C 152	5.74	9.68	18.30	20.99	21.19	20.73	20.55	20.54
GC 3	4.58	12.84	18.08	19.51	19.79	17.99	17.60	17.59
Mean	5.72	10.65	18.07	19.89	20.14	19.37	18.89	18.88
SE _±	0.32	0.75	0.64	0.34	0.30	0.29	0.25	0.25
CD at 5%	1.00	2.30	NS	1.05	0.92	0.90	0.77	0.77

The general form of the equation for pod girth was Y (pod girth) = $-b_0 + b_1X - b_2X^2 + b_3X^3$ for Phule Pandhari and C 152, whereas, Y (pod girth) = $b_0 - b_1X + b_2X^2 - b_3X^3$ for VCM 8, Konkan Safed and GC 3. The genotypes, Phule Pandhari and C 152 has

extremely negative value of b_0 but had maximum value of b_1 which suggested that there was a rapid increase in pod girth during the course of growth from the extremely small value at 0 times i.e. at anthesis. In contrast, VCM 8 had higher magnitude of b_0 and low magnitude of b_1 which suggested that at the time of setting of pod itself and high pod girth. The coefficient of determination (R^2) was non significant for all the genotypes indicated that the cubic polynomial was not appropriately fit for pod girth in all the genotypes.

Table 8. Values of regression coefficient of polynomials fitted for pod girth in cowpea genotypes from the stage of flowering

Genotypes	Values of regression co-efficient				R^2
	b_0	b_1	b_2	b_3	
VCM 8	75.8356 (52.05)	-23.5988 (14.48)	2.2943 (1.22)	-0.0645 (0.03)	0.7633
Konkan Safed	25.9281 (64.32)	-6.8991 (15.86)	0.6304 (1.18)	-0.0153 (0.03)	0.6366
Phule Pandhari	-40.9741 (62.11)	13.7311 (18.26)	-1.2706 (1.63)	0.0367 (0.04)	0.6973
C 152	-5.2380 (48.40)	2.3387 (12.98)	-0.1860 (1.05)	0.0061 (0.03)	0.6612
GC 3	73.0654 (50.08)	-24.4665 (16.36)	2.2774 (1.43)	-0.0604 (0.04)	0.6599

Figures in parentheses indicate SE values of variate.

4.1.4. Pod diameter

The periodical changes and constants of polynomials in pod diameter of cowpea genotypes are presented in Table 9 and 10. The differences among the genotypes for pod length were statistically significant at different stages of growth except at 9 DAF.

The genotype Konkan Safed (2.07 mm) recorded highest pod diameter at 3 DAF followed by VCM 8 (1.90 mm) and Phule Pandhari (1.84 mm). However, at 6 DAF, GC 3 (4.09 mm) and VCM

8 (3.34 mm) were found to be superior for higher pod diameter. At 9 DAF, Phule Pandhari (5.92 mm) and VCM 8 (5.85 mm) maintained higher pod diameter. The genotype C 152 maintained highest pod diameter at 12th (6.68 mm), 15th (6.74 mm), 18th (6.60 mm), 21st (6.54 mm) and 24th DAF (6.53 mm), respectively. The genotype VCM 8 at 12th (6.21 mm), 15th (5.90 mm) and 18th DAF (5.62 mm) and GC 3 at 21st (5.60 mm) and 24th DAF (5.60 mm) showed least pod diameter. The rate of increase for pod girth was higher in GC 3 (0.87 mm/day) and VCM 8 (0.48 mm/day) between 3 and 6 DAF, however, it was higher in C 152 (0.91 mm/day) and Phule Pandhari (0.89 mm/day) at 6-9 DAF (Appendix-I). Konkan Safed maintained higher rate for increasing pod diameter at 9-12 (0.31 mm/day) and 12-15 DAF (0.12 mm/day). After 15 DAF, the rate was minimized due losses in moisture content from the pods towards maturity.

Table 9. Periodical changes in pod diameter of cowpea genotypes

Genotype \ DAF	Pod diameter (mm)							
	3	6	9	12	15	18	21	24
VCM 8	1.90	3.34	5.85	6.21	5.90	5.62	5.62	5.62
Konkan Safed	2.07	3.19	5.40	6.34	6.70	6.60	6.03	6.03
Phule Pandhari	1.84	3.25	5.92	6.21	6.40	6.27	6.26	6.25
C 152	1.83	3.08	5.82	6.68	6.74	6.60	6.54	6.53
GC 3	1.46	4.09	5.75	6.21	6.30	5.73	5.60	5.60
Mean	1.82	3.39	5.75	6.33	6.41	6.16	6.01	6.01
SE _±	0.10	0.24	0.20	0.11	0.10	0.09	0.08	0.08
CD at 5%	0.32	0.73	NS	0.33	0.29	0.29	0.25	0.24

The form of equation for pod diameter was Y (pod diameter) = $-b_0 + b_1X - b_2X^2 + b_3X^3$ for Phule Pandhari and C 152, whereas, Y (pod diameter) = $b_0 - b_1X + b_2X^2 - b_3X^3$ for VCM 8, Konkan Safed and GC 3. The genotypes, Phule Pandhari and C 152 has extremely negative value of b_0 but had maximum value of b_1 which suggested that there was a rapid increase in pod diameter during the course

of growth from the extremely small value at 0 times i.e. at anthesis. In contrast, VCM 8 and GC 3 had higher magnitude of b_0 and low magnitude of b_1 which suggested that at the time of setting of pod itself and high pod girth. The coefficient of determination (R^2) was non significant for all the genotypes indicated that the cubic polynomial was not appropriately fit for pod diameter in all the genotypes.

Table 10. Values of regression coefficient of polynomials fitted for pod diameter in cowpea genotypes from the stage of flowering

Genotypes	Values of regression coefficient				R^2
	b_0	b_1	b_2	b_3	
VCM 8	74.9339 (51.89)	-73.3793 (45.43)	22.4462 (12.11)	-1.9852 (1.001)	0.7610
Konkan Safed	25.7592 (64.04)	-21.5789 (49.67)	6.2113 (11.66)	-0.4767 (0.86)	0.6358
Phule Pandhari	-41.0628 (61.99)	43.2265 (57.23)	-12.5676 (16.00)	1.1419 (1.36)	0.6983
C 152	-4.9657 (46.69)	7.0693 (40.99)	-1.7535 (10.36)	0.1806 (0.81)	0.6602
GC 3	73.1137 (50.35)	-76.8262 (51.64)	22.4463 (14.19)	-1.8704 (1.17)	0.6586

Figures in parentheses indicate SE values of variate.

4.1.5. Polar diameter of seed

The periodical changes and constants of polynomials in polar diameter of seed of cowpea genotypes are presented in Table 11 and 12. The differences among the genotypes for polar diameter were statistically significant at various stages of growth except at 9 and 15 DAF.

The genotype, Phule Pandhari and C 152 recorded maximum and minimum polar diameter of seed at 3 (0.69 & 0.062 mm), 6 (3.01 & 2.71 mm) and 9 DAF (6.40 & 5.76 mm), respectively. At 12 DAF, VCM 8 had maximum polar diameter (8.21 mm) than other

genotypes, however, it had minimum polar diameter of seed at 18 (5.48 mm), 21 (0.546 mm) and 24 DAF (5.45 mm) than rest of the genotypes. The genotypes, Konkan Safed had minimum polar diameter of seed at 12 DAF (6.78 mm), however, at advancing stages at 18 (8.44 mm), 21 (7.14 mm) and 24 DAF (7.13 mm) it maintained higher polar diameter of seed than other genotypes. The rate of increase for polar diameter of seed was higher in Phule Pandhari at 3 to 6 DAF (0.77 mm/day) and 6 to 9 DAF (1.13 mm/day), however, it was higher in C 152 and VCM 8 (0.70 mm/day) at 9-12 DAF (0.31 mm/day) (Appendix-I). Konkan Safed (0.58 mm/day) and C 152 (0.30 mm/day) maintained higher rate for increasing polar diameter of seed at 12-15 DAF,. After 15 DAF, the rate was minimized due losses in moisture content from the seeds towards maturity.

Table 11. Periodical changes in polar diameter of seed of cowpea genotypes

Genotype \ DAF	Polar diameter of seed (mm)							
	3	6	9	12	15	18	21	24
VCM 8	0.66	2.88	6.12	8.21	7.94	5.48	5.46	5.45
Konkan Safed	0.68	2.94	6.27	6.78	8.53	8.44	7.14	7.13
Phule Pandhari	0.69	3.01	6.40	7.86	8.38	6.56	6.45	6.45
C 152	0.62	2.71	5.76	7.85	8.77	7.42	6.88	6.87
GC 3	0.68	2.95	6.28	7.87	8.63	6.86	6.41	6.40
Mean	0.67	2.90	6.16	7.71	8.45	6.95	6.47	6.46
SE _±	0.02	0.08	0.18	0.21	0.26	0.25	0.14	0.14
CD at 5%	0.06	0.26	NS	0.63	NS	0.77	0.45	0.44

The form of equation for seed length was Y (seed length) = $b_0 - b_1X + b_2X^2 - b_3X^3$. In VCM 8 the value of b_1 was highest whereas b_0 was lowest. It means that there was faster seed growth rate in this variety. In contrast, C 152 exhibited least value for b_1 whereas high b_0 indicated the slower rate of seed growth. From the basis of

polynomial fittings, C 152 has slower rate of seed length increase next to Konkan Safed followed by Phule Pandhari and GC 3. The coefficient of determination (R^2) for polar diameter of seed against time interval was non significant for all the genotypes.

Table 12. Values of regression co-efficient of polynomials fitted for Polar diameter of seed in cowpea genotypes from the stage of flowering

Genotypes	Values of regression co-efficient				R^2
	b_0	b_1	b_2	b_3	
VCM 8	3.0628 (11.31)	-1.9364 (12.33)	1.7893 (3.17)	-0.1731 (0.23)	0.6047
Konkan Safed	5.4260 (10.12)	-3.9384 (10.02)	1.5443 (2.36)	-0.1075 (0.16)	0.6579
Phule Pandhari	4.9283 (10.92)	-4.3087 (11.11)	2.1209 (2.69)	-0.1782 (0.19)	0.6212
C 152	5.5424 (9.28)	-4.6340 (9.19)	1.9863 (2.17)	-0.1534 (0.15)	0.6756
GC 3	4.2346 (10.85)	-3.1450 (10.83)	1.7528 (2.56)	-0.1472 (0.17)	0.6101

Figures in parentheses indicate SE values of variate.

4.1.6. Equatorial diameter of seed

The periodical changes and constants of polynomials for equatorial diameter of seed in cowpea genotypes are presented in Table 13 and 14. The differences among the genotypes for equatorial diameter of seed were statistically significant at various stages of growth except at 9 DAF.

The genotype, GC 3 and VCM 8 recorded maximum and minimum equatorial diameter of seed at 3 (0.27 & 0.24 mm), 6 (1.44 & 1.27 mm) and 9 DAF (3.52 & 3.09 mm), respectively. C 152 at 12 (4.81 mm) and 15 DAF (4.78 mm); Konkan Safed at 18 DAF (4.66 mm) and Phule Pandhari at 21 (4.01 mm) and 24 DAF (4.01 mm) recorded maximum equatorial diameter of seed. Whereas, Konkan Safed at 12 DAF (3.81 mm) and VCM 8 at 15 (4.05 mm),

18 (3.16 mm), 21 (3.11 mm) and 24 DAF (3.11 mm) recorded minimum equatorial diameter of seed. The rate of increase for equatorial diameter of seed was higher in GC 3 at 3 to 6 (0.39 mm/day) and 6 to 9 DAF (0.69 mm/day), however, it was higher in Phule Pandhari (0.57 mm/day) and VCM 8 (0.39 mm/day) at 9-12 DAF (Appendix-I). At 12-15 DAF, Konkan Safed (0.28 mm/day) maintained higher rate for increasing equatorial diameter of seed. After 15 DAF, the rate was minimized due losses in moisture content from the seeds towards maturity.

Table 13: Periodical changes in equatorial diameter of seed of cowpea genotypes

DAF Genotype	Equatorial diameter of seed (mm)							
	3	6	9	12	15	18	21	24
VCM 8	0.24	1.27	3.09	4.26	4.05	3.16	3.11	3.11
Konkan Safed	0.26	1.36	3.30	3.81	4.66	4.66	3.87	3.86
Phule Pandhari	0.27	1.40	3.42	4.65	4.73	4.17	4.01	4.01
C 152	0.24	1.28	3.11	4.81	4.78	4.27	4.00	4.00
GC 3	0.27	1.44	3.52	4.24	4.42	4.06	3.82	3.82
Mean	0.26	1.35	3.29	4.35	4.53	4.07	3.76	3.76
SE _±	0.01	0.07	0.16	0.15	0.11	0.07	0.07	0.07
CD at 5%	0.04	0.21	NS	0.47	0.33	0.22	0.23	0.23

The periodical changes for seed diameter, the form of equation for equatorial diameter of seed was $Y = b_0 - b_1X + b_2X^2 - b_3X^3$. In C 152 and VCM 8 the value of b_1 was highest whereas b_0 was lowest revealed that there was faster rate of increase in seed diameter. In contrast, Konkan Safed exhibited least value for b_1 whereas high b_0 indicated the slower rate of increase in equatorial diameter of seed. From the basis of polynomial fittings, VCM 8 and Konkan Safed had slower rate of increase in equatorial diameter of seed. The value for coefficient of determination (R^2) for equatorial diameter of seed was non significant for all the genotypes.

Table 14: Values of regression co-efficient of polynomials fitted for seed diameter in cowpea genotypes from the stage of flowering

Genotypes	Values of regression co-efficient				R ²
	b ₀	b ₁	b ₂	b ₃	
VCM 8	4.0267 (8.54)	-5.7943 (18.56)	7.3559 (9.12)	-1.3013 (1.25)	0.6684
Konkan Safed	4.4549 (8.58)	-4.6646 (16.57)	4.1866 (7.28)	-0.5556 (0.90)	0.6532
Phule Pandhari	5.3493 (8.38)	-8.1263 (15.94)	6.4854 (7.01)	-0.9184 (0.88)	0.6749
C 152	6.1250 (6.96)	-10.4750 (13.38)	7.6976 (5.8661)	-1.0722 (0.72)	0.7514
GC 3	4.5189 (9.21)	-6.3668 (18.60)	6.1247 (8.98)	-0.9384 (1.24)	0.6210

Figures in parentheses indicate SE values of variate.

4.1.7. Pod volume

The periodical changes and constants of polynomials in pod volume of cowpea genotypes are presented in Table 15 and 16. The differences among the genotypes for pod volume were statistically significant at various stages of growth except at 9 DAF.

The genotypes, Konkan Safed at 3 (0.182 ml), 18 (4.068 ml), 21 (3.253 ml) and 24 DAF (3.253 ml); GC 3 at 6 DAF (0.659 ml) and C 152 at 9 (2.698 ml), 12 (4.646 ml) and 15 DAF (4.251) recorded the highest pod volume. However, VCM 8 recorded minimum pod volume at 3 (0.121 ml), 6 (0.323 ml), 12 (3.037 ml), 15 (2.135 ml), 18 (1.888 ml), 21 (1.828 ml) and 24 DAF (1.810 ml). At 9 DAF, Phule Pandhari (2.053 ml) had minimum pod volume. The rate of increase for pod volume was higher in Phule Pandhari at 3 to 6 DAF (0.13 ml/day), however, it was higher in C 152 (0.76 ml/day) at 6 to 9 DAF. At 9-12 DAF, C 152 (0.65 ml/day) and Konkan Safed (0.52 ml/day) maintained higher rate of increase in pod volume. At 12-15 DAF, Phule Pandhari (0.88 ml/day) had higher rate for increasing

pod volume. After 15 DAF, the rate was minimized due losses in moisture content from the pods towards maturity (Appendix-I).

Table 15. Periodical changes in pod volume of cowpea genotypes

Genotype \ DAF	Pod volume (ml)							
	3	6	9	12	15	18	21	24
VCM 8	0.121	0.323	2.470	3.037	2.135	1.888	1.828	1.810
Konkan Safed	0.182	0.439	2.137	3.704	4.115	4.068	3.253	3.253
Phule Pandhari	0.123	0.502	2.053	3.279	3.820	2.993	2.638	2.638
C 152	0.152	0.411	2.698	4.646	4.251	3.458	3.043	3.043
GC 3	0.154	0.659	2.442	3.110	3.973	2.594	2.249	2.249
Mean	0.146	0.467	2.360	3.555	3.659	3.000	2.602	2.598
SE _±	0.013	0.045	0.185	0.183	0.140	0.093	0.081	0.081
CD at 5%	0.039	0.138	NS	0.564	0.432	0.287	0.250	0.249

Table 16: Values of regression co-efficient of polynomials fitted for pod volume in cowpea genotypes from the stage of flowering

Genotypes	Values of regression co-efficient				R ²
	b ₀	b ₁	b ₂	b ₃	
VCM 8	-7.2186 (5.20)	65.0861* (23.81)	-39.5483 (17.79)	6.6118 (3.49)	0.8660*
Konkan Safed	7.0844 (6.56)	-13.3677 (19.60)	11.0773 (10.48)	-1.7872 (1.51)	0.7500
Phule Pandhari	4.1294 (6.94)	-2.6522 (21.92)	6.6399 (12.77)	-1.3907 (2.00)	0.6816
C 152	5.9327 (7.12)	-8.7423 (24.41)	8.0962 (12.06)	-1.2836 (1.55)	0.7190
GC 3	-2.7365 (8.52)	25.1454 (24.06)	-9.7477 (13.72)	1.1264 (2.07)	0.5939

Figures in parentheses indicate SE values of variate.

An attempt to fit polynomial of changes in pod volume during ontogeny against time from flowering indicated that the value of R² was significant for VCM 8 (0.8660). The genotypes, VCM 8 and GC 3 showed cubic polynomial equation as Y (pod volume) = $-b_0 + b_1 - b_2 + b_3$, whereas, Konkan Safed, Phule Pandhari and C 152 as Y

(pod volume) $= + b_0 - b_1X + b_2X^2 - b_3X^3$. In VCM 8 and GC 3, the value of b_1 was highest whereas b_0 was lowest revealed that there was faster rate of increase in pod volume.

4.1.8. Seed volume

The periodical changes and constants of polynomials in seed volume of cowpea genotypes are presented in Table 17 and 18. The differences among the genotypes for seed volume were statistically significant at various stages of growth except at 12 DAF.

Table 17. Periodical changes in seed volume of cowpea genotypes

Genotype \ DAF	Seed volume (ml)							
	3	6	9	12	15	18	21	24
VCM 8	0.003	0.028	0.111	0.184	0.144	0.119	0.117	0.116
Konkan Safed	0.009	0.032	0.085	0.204	0.197	0.202	0.181	0.181
Phule Pandhari	0.006	0.031	0.085	0.178	0.186	0.127	0.122	0.122
C 152	0.005	0.031	0.089	0.206	0.197	0.145	0.143	0.143
GC 3	0.005	0.038	0.118	0.172	0.186	0.143	0.119	0.119
Mean	0.006	0.032	0.097	0.189	0.182	0.147	0.136	0.136
SE _±	0.000	0.001	0.005	0.013	0.002	0.005	0.004	0.004
CD at 5%	0.001	0.002	0.014	NS	0.019	0.014	0.012	0.012

The genotypes, Konkan Safed at 3 (0.009 ml), 15 (0.197 ml), 18 (0.202 ml), 21 (0.181 ml) and 24 DAF (0.181 ml); GC 3 at 6 (0.038 ml) and 9 DAF (0.118 ml) and C 152 at 12 (0.206 ml) and 15 DAF (0.197) recorded higher seed volume. However, VCM 8 at 3 (0.003 ml), 6 (0.028 ml), 15 (0.144 ml), 18 (0.119 ml), 21 (0.117 ml) and 24 DAF (0.116 ml) had minimum seed volume. At 9 DAF Konkan Safed and Phule Pandhari (0.085 ml) and at 12 DAF, GC 3 (0.172 ml) had minimum seed volume. The rate of increase for seed volume was higher in GC 3 at 3 to 6 (0.011 ml/day) and 6 to 9 DAF (0.027 ml/day), however, it was higher in Konkan Safed (0.040 ml/day) at 6 to 9 DAF. At 9-12 DAF, C 152 (0.65 ml/day) and Konkan Safed (0.52 ml/day) maintained higher rate of increase in

pod volume. At 12-15 DAF, GC 3 (0.005 ml/day) and Phule Pandhari (0.03 ml/day) maintained higher rate for increasing seed volume. After 15 DAF, the rate was minimized due losses in moisture content from the pods towards maturity (Appendix-I).

An attempt to fit polynomial of changes in pod volume during ontogeny against time from flowering indicated that the values of R^2 were significant for Konkan Safed (0.8931), Phule Pandhari (0.8253) and C 152 (0.9035). The form of equation for seed volume was Y (seed volume) = $b_0 + b_1X + b_2X^2 - b_3X^3$ for VCM 8 and GC 3, however, it was $Y = b_0 - b_1X + b_2X^2 - b_3X^3$ for Konkan Safed, Phule Pandhari and C 152. In VCM 8 and GC 3 the value of b_1 was highest whereas b_0 was lowest revealed that there was faster rate of increase in seed volume. In contrast, Konkan Safed exhibited least value for b_1 whereas high b_0 indicated the slower rate of increase in seed volume.

Table 18: Values of regression co-efficient of polynomials fitted for seed volume (ml) in cowpea genotypes from the stage of flowering

Genotypes	Values of regression co-efficient				R^2
	b_0	b_1	b_2	b_3	
VCM 8	2.5635 (6.45)	103.2520 (443.64)	1091.879 (5536.30)	-7533.2 (18142)	0.6601
Konkan Safed	6.5358 (4.22)	-261.127 (207.14)	5295.112 (24.02.8)	-18771 (7585.6)	0.8931*
Phule Pandhari	4.7767 (5.13)	-161.859 (295.21)	4669.76 (3622.59)	-19226 (11885)	0.8252*
C 152	5.0566 (3.48)	-169.207 (179.70)	4081.217 (1978.41)	-15021 (5860.2)	0.9035*
GC 3	2.0688 (7.39)	93.2513 (431.69)	1184.07 (5211.9)	-7401.4 (16941)	0.6191

Figures in parentheses indicate SE values of variate.

4.1.9. Fresh weight of pod wall

The periodical changes and constants of polynomials for fresh weight of pod wall are presented in Table 19 and 20. The differences among the genotypes for fresh weight of cowpea pod wall were statistically significant at various stages of growth except at 6 and 9 DAF.

Table 19. Periodical changes in fresh weight of cowpea pod wall

Genotype \ DAF	Fresh weight of cowpea pod wall (g)							
	3	6	9	12	15	18	21	24
VCM 8	0.073	0.450	1.674	1.215	0.731	0.371	0.311	0.272
Konkan Safed	0.188	0.494	1.427	1.631	1.087	0.997	0.532	0.398
Phule Pandhari	0.162	0.434	1.271	1.584	0.961	0.393	0.366	0.342
C 152	0.183	0.403	1.519	1.487	1.012	0.582	0.548	0.543
GC 3	0.173	0.609	1.381	1.987	1.451	0.498	0.405	0.370
Mean	0.156	0.478	1.454	1.581	1.048	0.568	0.432	0.385
SE _±	0.0183	0.063	0.108	0.091	0.054	0.048	0.012	0.010
CD at 5%	0.0563	NS	NS	0.280	0.165	0.149	0.036	0.032

The genotypes, Konkan Safed at 3 (0.188 g) and 18 DAF (0.997 g); GC 3 at 6 (0.609 g), 12 (1.987 g) and 15 DAF (1.451 g); VCM 8 at 9 DAF (1.674 g) and C 152 at 21 (0.548 g) and 24 DAF (0.543 g) had highest fresh weight of pod wall. Whereas, VCM 8 at 3 (0.073 g), 12 (1.215 g), 15 (0.731 g), 18 (0.371 g), 21 (0.311 g) and 24 DAF (0.272 g) had minimum fresh weight of pod wall. C 152 (0.403 g) at 6 DAF and Phule Pandhari (1.271 g) at 12 DAF recorded minimum fresh weight of pod wall. The rate of increase for fresh weight of pod wall was higher in GC 3 (0.15 g/day) and VCM 8 (0.13 g/day) at 3 to 6 DAF, however, it was higher in VCM 8 (0.41 g/day) and C 152 (0.37 g/day) at 6 to 9 DAF. At 9-12 DAF, Phule Pandhari (0.11 g/day) recorded higher rate of increase in fresh weight of pod wall. After 12 DAF, the rate was minimized due

losses in moisture content from the pods towards maturity (Appendix-I).

Table 20: Values of regression co-efficient of polynomials fitted for fresh weight of pod wall in cowpea genotypes from the stage of flowering

Genotypes	Values of regression co-efficient				R ²
	b ₀	b ₁	b ₂	b ₃	
VCM 8	4.0870 (11.02)	57.7206 (56.46)	-73.874 (77.25)	24.7282 (29.52)	0.2673
Konkan Safed	-12.4006 (18.03)	109.7933 (79.46)	-117.321 (97.24)	36.1497 (34.97)	0.3925
Phule Pandhari	-9.4125 (17.95)	115.6289 (84.62)	-141.69 (106.6)	48.7962 (39.44)	0.3410
C 152	-17.4924 (13.28)	123.8729 (63.62)	-127.875 (90.03)	38.4236 (36.27)	0.6844
GC 3	0.7557 (17.30)	57.3054 (67.77)	-59.0862 (68.33)	16.7453 (20.10)	0.1729

Figures in parentheses indicate SE values of variate.

An attempt to fit polynomial of changes in fresh weight of pod wall during ontogeny against time from flowering indicated the values of R² were non significant for all the genotypes. The cubic polynomial equation for this character is Y (fresh weight of pod wall) = $b_0 + b_1X - b_2X^2 + b_3X^3$ for VCM 8 and GC 3, whereas, it was $Y = -b_0 + b_1X - b_2X^2 + b_3X^3$ for Konkan safed, Phule Pandhari and C 152. In VCM 8 and GC 3, the value of b_1 was lowest whereas b_0 was highest revealed that there was slower rate of increase in fresh weight of pod wall. In contrast, C 152 followed by Konkan Safed and Phule Pandhari had faster rate of increase in fresh weight of pod wall.

4.1.10. Fresh weight of pod

The periodical changes and constants of polynomials in fresh weight of pod of cowpea genotypes at various stages of growth are presented in Table 21 and 22. The differences among the genotypes

for fresh weight of pod were statistically significant at various stages of growth except at 6 and 9 DAF.

The genotypes, Konkan Safed at 3 (0.199 g) and 18 DAF (3.481 g); GC 3 at 6 (0.712 g) and 9 DAF (2.274 g) and C 152 at 12 (3.994 g), 15 (4.003 g), 21 (2.128 g) and 24 DAF (2.057 g) had highest fresh weight of pod. Whereas, VCM 8 at 3 (0.077 g), 9 (1.832 g), 12 (2.659 g), 15 (1.930 g), 18 (1.352 g), 21 (1.192 g) and 24 DAF (1.039 g) had minimum fresh weight of pod. At 6 DAF, C 152 (0.504 g) had minimum fresh weight of pod. The genotype, GC 3 maintained higher rate of increase for fresh weight of pod at 3 to 6 (0.18 g/day), 6 to 9 (0.52 g/day) and 9 to 12 DAF (0.44 g/day). At 12-15 DAF, Phule Pandhari (0.13 g/day) recorded higher rate of increase in fresh weight of pod. After 15 DAF, the rate was minimized due losses in moisture content from the pods towards maturity (Appendix-I).

Table 21. Periodical changes in fresh weight of cowpea pod

Genotype \ DAF	Fresh weight of cowpea pod (g)							
	3	6	9	12	15	18	21	24
VCM 8	0.077	0.564	1.832	2.659	1.930	1.352	1.192	1.039
Konkan Safed	0.199	0.619	2.161	3.444	3.517	3.481	2.110	1.740
Phule Pandhari	0.167	0.533	1.940	2.704	3.079	1.605	1.500	1.433
C 152	0.190	0.504	1.984	3.994	4.003	2.352	2.128	2.057
GC 3	0.179	0.712	2.274	3.599	3.746	1.875	1.748	1.596
Mean	0.162	0.586	2.038	3.280	3.255	2.133	1.736	1.573
SE _±	0.019	0.068	0.264	0.208	0.136	0.101	0.074	0.048
CD at 5%	0.059	NS	NS	0.640	0.419	0.311	0.229	0.147

An attempt to fit polynomial of changes in fresh weight of pod wall during ontogeny against time from flowering indicated that the values of R^2 were non significant for all the genotypes. The cubic polynomial equation for this character was Y (fresh weight of pod) = $-b_0 + b_1X - b_2X^2 + b_3X^3$ for all genotypes except C 152. The genotype,

Phule Pandhari, GC 3 and Konkan safed recorded highest value of b_1 and lowest value of b_0 for fresh weight of pod indicated the faster rate of increase in fresh weight of pods.

Table 22. Values of regression co-efficient of polynomials fitted for fresh weight of pod in cowpea genotypes from the stage of flowering

Genotypes	Values of regression co-efficient				R^2
	b_0	b_1	b_2	b_3	
VCM 8	-2.6128 (7.09)	43.7962 (23.33)	-28.3505 (20.62)	5.2061 (4.94)	0.6159
Konkan Safed	-5.2299 (10.96)	33.6342 (34.49)	-15.3638 (22.72)	2.1153 (3.94)	0.5881
Phule Pandhari	-8.614 (8.05)	53.5074 (26.09)	-32.4561 (19.97)	5.6758 (4.09)	0.6863
C 152	2.7388 (10.05)	3.0558 (34.32)	4.2869 (21.13)	-1.0946 (3.29)	0.6756
GC 3	-6.7087 (8.64)	41.4332 (24.16)	-21.0062 (15.95)	3.0502 (2.73)	0.6338

Figures in parentheses indicate SE values of variate.

4.1.11. Fresh weight of seeds/ pod

The periodical changes and constants of polynomials for fresh weight of seeds/ pod of cowpea genotypes are presented in Table 23 and 24. The differences among the genotypes for fresh weight of seeds/ pod were statistically significant at various stages of growth except at 6 and 9 DAF.

The genotypes, Konkan Safed at 3 (0.011 g), 18 (2.434 g) and 21 DAF (1.678 g); GC 3 at 6 (0.128 g) and 9 DAF (0.893 g) and C 152 at 12 (2.507 g), 15 (2.838 g) and 24 DAF (1.513 g) had highest fresh weight of seeds/ pod. Whereas, VCM 8 at 3 (0.004 g), 9 (0.633 g), 12 (1.444 g), 15 (1.199 g), 18 (0.856 g), 21 (0.857 g) and 24 DAF (0.767 g) had minimum fresh weight of seeds /pod. At 6 DAF, C 152 (0.101 g) had minimum fresh weight of seeds/ pod. The genotype, GC 3 maintained higher rate of increase for fresh weight

of seeds/pod at 3 to 6 (0.040 g/day) and 6 to 9 DAF (0.26 g/day), however, it was higher in C 152 (0.60 g/day) and Konkan Safed (0.36) at 9 to 12 DAF. At 12-15 DAF, CG 3 (0.23 g/day) and Phule Pandhari (0.21 g/day) recorded the rate of increase in fresh weight of seeds/pod. After 15 DAF, the rate was minimized due losses in moisture content from the pods towards maturity (Appendix-I).

Table 23. Periodical changes in fresh weight of cowpea seeds/pod

Genotype \ DAF	Fresh weight of cowpea seeds/pod (g)							
	3	6	9	12	15	18	21	24
VCM 8	0.004	0.114	0.633	1.444	1.199	0.856	0.857	0.767
Konkan Safed	0.011	0.126	0.719	1.813	2.431	2.434	1.678	1.342
Phule Pandhari	0.005	0.102	0.670	1.483	2.118	1.211	1.125	1.091
C 152	0.007	0.101	0.716	2.507	2.838	1.769	1.582	1.513
GC 3	0.006	0.128	0.893	1.613	2.295	1.377	1.343	1.226
Mean	0.007	0.114	0.726	1.772	2.176	1.530	1.317	1.188
SE $\pm$	0.0020	0.012	0.114	0.147	0.091	0.064	0.063	0.045
CD at 5%	0.0063	NS	NS	0.452	0.282	0.196	0.195	0.139

Table 24. Values of regression co-efficient of polynomials fitted for fresh weight of seeds/ pod in cowpea genotypes from the stage of flowering

Genotypes	Values of regression co-efficient				R ²
	b ₀	b ₁	b ₂	b ₃	
VCM 8	3.4269 (4.44)	10.1132 (42.32)	27.3293 (74.71)	-21.2875 (33.27)	0.7381
Konkan Safed	2.8899 (4.43)	16.7116 (22.15)	-3.6273 (21.99)	-0.4251 (5.65)	0.7068
Phule Pandhari	2.7586 (4.50)	24.4409 (27.73)	-10.8756 (33.94)	0.8842 (10.37)	0.6858
C 152	2.9834 (3.43)	16.2821 (15.70)	-2.6632 (14.23)	-0.6706 (3.27)	0.8050
GC 3	3.1557 (4.83)	15.5929 (30.15)	-2.0232 (33.57)	-1.1574 (9.33)	0.6551

Figures in parentheses indicate SE values of variate.

An attempt to fit polynomial of changes in fresh weight of seeds/ pod during ontogeny against time from flowering indicated that the values of R^2 were non significant for all the genotypes. The cubic polynomial equation was Y (fresh weight of seeds/ pod) = $b_0 + b_1X + b_2X^2 - b_3X^3$ for VCM 8, $Y = b_0 + b_1X - b_2X^2 - b_3X^3$ for Konkan Safed, C 152 and GC 3 and $Y = b_0 + b_1X - b_2X^2 - b_3X^3$ for Phule Pandhari. The genotype, Phule Pandhari, Konkan Safed and C 152 had highest value of b_1 and lowest b_0 's were indicated the faster rate of increase in fresh weight of seeds/ pods.

4.1.12. Dry weight of cowpea pod wall

The periodical changes and constants of polynomials for dry weight of pod wall of cowpea genotypes are presented in Table 25 and 26. The differences among the genotypes for dry weight of pod wall were statistically significant at various stages of growth except at 6 and 9 DAF.

Table 25. Periodical changes in dry weight of cowpea pod wall

Genotype \ DAF	Dry weight of cowpea pod wall (g)							
	3	6	9	12	15	18	21	24
VCM 8	0.021	0.067	0.200	0.209	0.223	0.236	0.264	0.266
Konkan Safed	0.027	0.073	0.185	0.300	0.347	0.357	0.392	0.395
Phule Pandhari	0.023	0.079	0.181	0.271	0.307	0.319	0.327	0.337
C 152	0.023	0.059	0.191	0.392	0.459	0.525	0.530	0.540
GC 3	0.024	0.100	0.191	0.219	0.273	0.334	0.358	0.368
Mean	0.024	0.076	0.190	0.278	0.322	0.354	0.374	0.381
SE _±	0.004	0.009	0.027	0.014	0.011	0.015	0.010	0.010
CD at 5%	0.011	NS	NS	0.045	0.033	0.047	0.032	0.031

The genotypes, Konkan Safed at 3 DAF (0.027 g); GC 3 at 6 DAF (0.100 g); VCM 8 at 9 DAF (0.200 g) and C 152 at 12 (0.392 g), 15 (0.459 g), 18 (0.525 g), 21 (0.530 g) and 24 DAF (0.540 G) recorded highest dry weight of pod wall. Whereas, VCM 8 at 3 (0.021 g), 12 (0.209 g), 15 (0.223 g), 18 (0.236 g), 21 (0.264 g) and

24 DAF (0.266 g) had minimum dry weight of pod wall. At 6 and 9 DAF, C 152 (0.59 g) and Phule Pandhari (0.181 g) had minimum fresh weight of pod wall, respectively.

The values of coefficient of determination (R^2) were significant for all genotypes indicated cubic curve was appropriately fit for dry weight of pod wall. The cubic polynomial equation was Y (dry weight of pod wall) = $b_0 + b_1X - b_2X^2 + b_3X^3$ for VCM 8, C 152 and GC 3, while, $Y = -b_0 + b_1 - b_2 + b_3$ for Konkan Safed and Phule Pandhari as a good fit. The genotype, Phule Pandhari and Konkan Safed had highest value of b_1 and lowest value of b_0 revealed that the rate of increase in dry matter in pod wall was higher than other genotypes.

Table 26. Values of regression co-efficient of polynomials fitted for dry weight of pod wall in cowpea genotypes from the stage of flowering

Genotypes	Values of regression co-efficient				R^2
	b_0	b_1	b_2	b_3	
VCM 8	1.1439 (3.31)	117.79 (109.79)	-992.936 (806.42)	3244.14 (1694.83)	0.9697*
Konkan Safed	-0.2066 (1.81)	131.0958* (41.87)	-674.577 (225.93)	1241.283 (342.50)	0.9872*
Phule Pandhari	-0.9809 (2.26)	178.7677* (61.31)	-1173.7* (397.41)	2532.561* (719.30)	0.9812*
C 152	1.2858 (1.94)	92.1764 (37.53)	-350.494 (155.65)	465.3062 (176.82)	0.9739*
GC 3	1.6969 (1.86)	53.8680 (45.37)	-135.282 (273.07)	393.1094 (453.01)	0.9859*

Figures in parentheses indicate SE values of variate.

4.1.13. Dry weight of cowpea seeds/ pod

The periodical changes and constants of polynomials for dry weight of seeds/pod of cowpea genotypes are presented in Table 27 and 28. The differences among the genotypes for dry weight of seeds/ pod were statistically significant at various stages of growth except at 6 and 9 DAF.

The genotypes, Konkan Safed at 3 DAF (0.002 g); GC 3 at 6 (0.016 g) and 9 DAF (0.141 g); VCM 8 at 9 DAF (0.153 g) and C 152 at 12 (0.879 g), 15 (1.340 g), 18 (1.439 g), 21 (1.457 g) and 24 DAF (1.511 G) had highest dry weight of seeds/ pod. Whereas, Phule Pandhari at 6 (0.012 g) and 9 DAF (0.095 g); and VCM 8 at 12 (0.503 g), 15 (0.617 g), 18 (0.691 g), 21 (0.759 g) and 24 DAF (0.763 g) had minimum dry weight of seeds/ pod.

Table 27. Periodical changes in dry weight of cowpea seeds/pod

Genotype \ DAF	Dry weight of cowpea seeds/pod (g)							
	3	6	9	12	15	18	21	24
VCM 8	0.001	0.013	0.153	0.503	0.617	0.691	0.759	0.763
Konkan Safed	0.002	0.016	0.099	0.670	1.143	1.297	1.336	1.339
Phule Pandhari	0.001	0.012	0.095	0.461	1.011	1.043	1.067	1.073
C 152	0.001	0.013	0.107	0.879	1.340	1.439	1.457	1.511
GC 3	0.001	0.016	0.141	0.375	0.825	1.160	1.214	1.221
Mean	0.001	0.014	0.119	0.577	0.987	1.126	1.166	1.181
SE _±	0.0004	0.0012	0.0162	0.066	0.053	0.047	0.042	0.045
CD at 5%	0.0011	NS	NS	0.203	0.163	0.144	0.131	0.140

Table 28. Values of regression co-efficient of polynomials fitted for dry weight of seeds/ pod in cowpea genotypes from the stage of flowering

Genotypes	Values of regression co-efficient				R ²
	b ₀	b ₁	b ₂	b ₃	
VCM 8	4.0840* (0.97)	51.0555* (17.56)	-137.638 (54.15)	134.575* (44.05)	0.9825*
Konkan Safed	4.1408* (1.20)	54.0219* (17.44)	-94.135* (33.67)	47.6345* (16.15)	0.9694*
Phule Pandhari	3.4005* (1.10)	95.3655* (21.09)	-242.46* (59.50)	158.388* (38.68)	0.9732*
C 152	3.8227* (0.83)	64.2321* (13.29)	-103.10* (22.21)	45.8244* (9.27)	0.9856*
GC 3	4.1076* (1.24)	41.8780* (13.42)	-64.4067 (28.52)	34.4740 (15.47)	0.9687*

Figures in parentheses indicate SE values of variate.

The values for coefficient of determination (R^2) were highly significant for all genotypes. The cubic polynomial as a good fit for all the genotypes had form of equation was Y (dry weight of seeds/pod) = $b_0 + b_1X - b_2X^2 + b_3X^3$ for all the genotypes. The genotype, Phule Pandhari and C 152 had highest value of b_1 and lowest value of b_0 revealed that the rate of increase in dry matter in seeds/ pod was higher than other genotypes. In contrast, GC 3 exhibited highest value of b_0 and lowest value of b_1 indicated that, the rate of increase in dry weight of seeds/ pod was less than other genotypes.

4.1.14. Dry weight of cowpea pod

The periodical changes and constants of polynomials for dry weight of pod of cowpea genotypes are presented in Table 29 and 30. The differences among the genotypes for dry weight of pod were statistically significant at various stages of growth except at 9 DAF.

Table 29. Periodical changes in dry weight of cowpea pod

Genotype \ DAF	Dry weight of cowpea pod (g)							
	3	6	9	12	15	18	21	24
VCM 8	0.022	0.080	0.352	0.712	0.868	0.924	1.024	1.029
Konkan Safed	0.029	0.086	0.284	0.970	1.490	1.652	1.728	1.733
Phule Pandhari	0.024	0.071	0.276	0.732	1.318	1.362	1.393	1.410
C 152	0.024	0.072	0.298	1.271	1.799	1.964	2.012	2.050
GC 3	0.027	0.115	0.332	0.594	1.098	1.494	1.561	1.589
Mean	0.025	0.085	0.309	0.855	1.314	1.479	1.544	1.562
SE $\pm$	0.004	0.008	0.041	0.073	0.055	0.057	0.049	0.048
CD at 5%	0.012	0.024	NS	0.226	0.170	0.175	0.152	0.148

The genotypes, Konkan Safed at 3 DAF (0.029 g); GC 3 at 6 DAF (0.115 g); VCM 8 at 9 DAF (0.352 g) and C 152 at 12 (1.271 g), 15 (1.799 g), 18 (1.964 g), 21 (2.012 g) and 24 DAF (2.050 G) recorded highest dry weight of pod. Whereas, VCM 8 at 3 (0.022 g), 12 (0.712 g), 15 (0.868 g), 18 (0.924 g), 21 (1.024 g) and 24 DAF

(1.029 g) had minimum dry weight of pod. Phule Pandhari at 6 (0.071 g) and 9 DAF (0.276 g) had minimum dry weight of pod.

An attempt to fit polynomial of changes in dry weight of pod during ontogeny against time from flowering indicated that the values of R^2 were significant for all the genotypes. Thus, it showed cubic polynomial as a good fit for all the genotypes. The character showed cubic polynomial equation was Y (dry weight of seeds/pod) = $b_0 + b_1X - b_2X^2 + b_3X^3$ for all the genotypes. The genotype, Phule Pandhari and GC 3 had highest value of b_1 and lowest value of b_0 revealed that the initial rate of increase in dry weight of pod was higher than other genotypes.

Table 30. Values of regression co-efficient of polynomials fitted for dry weight of pod in cowpea genotypes from the stage of flowering

Genotypes	Values of regression co-efficient				R^2
	b_0	b_1	b_2	b_3	
VCM 8	2.6665* (1.10)	38.8741* (12.19)	-76.600* (27.38)	56.1574* (16.56)	0.9869*
Konkan Safed	2.2719 (1.27)	38.0410* (10.02)	-47.223* (13.89)	18.3991* (5.04)	0.9809*
Phule Pandhari	1.8066 (1.93)	52.9974* (19.16)	-87.2006 (36.30)	42.3039 (17.20)	0.9567*
C 152	2.6781 (1.23)	34.0661* (9.33)	-37.177* (10.81)	12.3245* (3.27)	0.9798*
GC 3	2.2688 (1.32)	32.2341* (9.07)	-35.374* (14.17)	14.4892 (5.84)	0.9799*

Figures in parentheses indicate SE values of variate.

4.1.15. Seed growth rate

Seed growth rate of cowpea genotypes at various stages of growth are presented in Table 31. The differences among the genotypes for seed growth rates were statistically significant at various stages of growth except at 6-9 DAF.

At 6-9 DAF, VCM 8 (0.0464 g/ day) had highest seed growth rate. Afterwards, C 152 maintained highest seed growth rates at 6-12 (0.2886 g/day), 6-15 (0.4423 g/day), 6-18 (0.4752 g/day), 6-21 (0.4870 g/day) and 6-24 DAF (0.4993 g/day). The genotypes, Phule Pandhari at 6-9 DAF (0.278 g/day), GC 3 at 6-12 (0.1196 g/day) had least seed growth rates. After that, VCM 8 had recorded minimum seed growth rates at 6-15 (0.2014 g/day), 6-18 (0.2258 g/day), 6-21 (0.2485) and 6-24 DAF (0.2499 g/day).

Table 31. Periodical seed growth rates as influenced by cowpea genotypes

Genotype \ DAF	Growth rate of cowpea seeds (g/day)					
	6-9	6-12	6-15	6-18	6-21	6-24
VCM 8	0.0464	0.1631	0.2014	0.2258	0.2485	0.2499
Konkan Safed	0.0279	0.2180	0.3758	0.4271	0.4402	0.4411
Phule Pandhari	0.0278	0.1498	0.3330	0.3438	0.3517	0.3537
C 152	0.0314	0.2886	0.4423	0.4752	0.4870	0.4993
GC 3	0.0416	0.1196	0.2696	0.3813	0.3992	0.4017
Mean	0.0350	0.1878	0.3244	0.3706	0.3853	0.3891
SE _±	0.0053	0.0221	0.0175	0.0154	0.0142	0.0149
CD at 5%	NS	0.0681	0.0539	0.0475	0.0439	0.0460

4.1.16. Pod growth rate

Pod growth rate of cowpea genotypes at various stages of growth are presented in Table 32. The differences among the genotypes for pod growth rates were statistically significant at various stages of growth except at 3-9 DAF.

At 3-6 DAF, GC 3 (0.0288 g/day) and at 3-9 DAF, VCM 8 (0.0464 g/ day) had highest pod growth rate. Afterwards, C 152 maintained highest pod growth rates at 3-12 (0.4154 g/day), 3-15 (0.5915 g/day), 3-18 (0.6464 g/day), 3-21 (0.6758 g/day) and 3-24 DAF (0.6823 g/day). The genotypes, Phule Pandhari at 3-6 (0.149 g/day) and 3-9 DAF (0.0831 g/day) and GC 3 at 3-12 (0.1885

g/day) had least pod growth rates. After that, VCM 8 had recorded minimum pod growth rates at 3-15 (0.2815 g/day), 3-18 (0.3002 g/day), 3-21 (0.3335) and 3-24 DAF (0.3353 g/day).

Table 32. Periodical pod growth rate as influenced by cowpea genotypes

Genotype \ DAF	Growth rate of cowpea pods (g/day)						
	3-6	3-9	3-12	3-15	3-18	3-21	3-24
VCM 8	0.0190	0.1095	0.2293	0.2815	0.3002	0.3335	0.3353
Konkan Safed	0.0174	0.0837	0.3122	0.4854	0.5397	0.5648	0.5667
Phule Pandhari	0.0149	0.0831	0.2350	0.4303	0.4451	0.4555	0.4610
C 152	0.0160	0.0914	0.4154	0.5915	0.6464	0.6758	0.6823
GC 3	0.0288	0.1013	0.1885	0.3566	0.4885	0.5108	0.5203
Mean	0.0192	0.0938	0.2761	0.4291	0.4840	0.5081	0.5131
SE _±	0.0027	0.0147	0.0254	0.0192	0.0184	0.0165	0.0157
CD at 5%	0.0084	NS	0.0783	0.0590	0.0567	0.0508	0.0484

4.1.17. Relative growth rate of seed

Relative growth rate of seed of cowpea genotypes at various stages of growth are presented in Table 33. The differences among the genotypes for relative growth rate of seed were statistically significant at 9-12, 15-18 and 21-24 DAF.

Table 33. Periodical relative growth rate of seeds as influenced by cowpea genotypes

Genotype \ DAF	Relative growth rate of seeds (g/g/day)						
	3-6	6-9	9-12	12-15	15-18	18-21	21-24
VCM 8	0.3487	0.3483	0.1756	0.0318	0.0167	0.0126	0.0008
Konkan Safed	0.3040	0.2684	0.2725	0.0840	0.0185	0.0044	0.0003
Phule Pandhari	0.3007	0.3031	0.2336	0.1137	0.0047	0.0033	0.0008
C 152	0.3192	0.3063	0.3056	0.0602	0.0112	0.0053	0.0036
GC 3	0.3381	0.3067	0.1261	0.1359	0.0484	0.0071	0.0009
Mean	0.3221	0.3066	0.2227	0.0851	0.0199	0.0065	0.0013
SE _±	0.0322	0.0197	0.0344	0.0246	0.0090	0.0037	0.0006
CD at 5%	NS	NS	0.1059	NS	0.0276	NS	0.0017

VCM 8 had higher relative growth rate of seed at 3-6 (0.3487 g/g/day), 6-9 (0.3483 g/g/day) and 18-21 DAF (0.0126 g/g/day). C 152 at 9-12 (0.3056 g/g/day) and 21-24 DAF (0.0036 g/g/day) and GC 3 at 12-15 (0.1359 g/g/day) and 15-18 DAF (0.0484 g/g/day) maintained maximum relative growth rate of seed. Whereas, Phule Pandhari at 3-6 (0.3007 g/g/day), 15-18 (0.0047 g/g/day) and 18-21 DAF (0.0033 g/g/day), Konkan Safed at 6-9 (0.2684 g/g/day) and 21-24 DAF (0.0003 g/g/day), GC 3 at 9-12 DAF (0.1261 g/g/day), VCM 8 at 12-15 DAF (0.0318 g/g/day) had least amount of relative growth rate of seeds.

4.1.18. Relative growth rate of pod

Relative growth rate of pod of cowpea genotypes at various stages of growth are presented in Table 34. The differences among the genotypes for relative growth rate of pod were statistically significant at 9-12, 15-18 and 21-24 DAF.

Table 34. Periodical relative growth rate of pods as influenced by cowpea genotypes

Genotype \ DAF	Relative growth rate of pods (g/g/day)						
	3-6	6-9	9-12	12-15	15-18	18-21	21-24
VCM 8	0.1753	0.2136	0.1027	0.0301	0.0097	0.0142	0.0007
Konkan Safed	0.1410	0.1738	0.1748	0.0654	0.0151	0.0065	0.0005
Phule Pandhari	0.1422	0.1934	0.1467	0.0851	0.0049	0.0033	0.0017
C 152	0.1594	0.2052	0.2106	0.0497	0.0132	0.0093	0.0029
GC 3	0.2086	0.1485	0.0795	0.1009	0.0435	0.0069	0.0028
Mean	0.1653	0.1869	0.1428	0.0662	0.0173	0.0080	0.0017
SE _±	0.0222	0.0242	0.0278	0.0182	0.0068	0.0034	0.0005
CD at 5%	NS	NS	0.0858	NS	0.0210	NS	0.0017

The genotypes, GC 3 at 3-6 (0.2086 g/g/day), 12-15 (0.1009 g/g/day) and 15-18 DAF (0.0435 g/g/day), VCM 8 at 6-9 (0.2136 g/g/day) and 18-21 DAF (0.0142 g/g/day) and C 152 at 9-12 (0.2106 g/g/day) and 21-24 DAF (0.0029 g/g/day) had higher

relative growth rate of pod. Whereas, Konkan Safed at 3-6 (0.1410 g/g/day) and 21-24 DAF (0.0005 g/g/day), GC 3 at 6-9 (0.1485 g/g/day) and 9-12 DAF (0.795 g/g/day), VCM 8 at 12-15 DAF (0.0301 g/g/day), Phule Pandhari at 15-18 (0.0049 g/g/day), 18-21 DAF (0.0033 g/g/day) had least amount of relative growth rate of pods.

4.1.19. Actual and effective pod development periods

Actual and effective pod development and lag periods of cowpea genotypes are presented in Table 35. The differences among the genotypes were statistically significant for all the parameters.

Table 35. Actual and effective pod development periods among cowpea genotypes

Genotypes	Actual pod development periods (APDP), days	Effective pod development periods (EPDP), days	Lag periods for pod development (days)
VCM 8	17.50	11.55	5.95
Konkan Safed	19.25	11.17	8.08
Phule Pandhari	19.50	11.68	7.82
C 152	17.25	10.99	6.26
GC 3	19.25	11.85	7.40
Mean	18.55	11.45	7.10
SE _±	0.86	0.78	1.09
CD at 5%	NS	NS	NS

Actual pod development periods (APDP) in cowpea genotypes ranged between 17.25 (C 152) to 19.50 (Phule Pandhari) days. The effective pod development periods (EPDP) amongst the genotype ranged between 10.99 (C 152) and 11.85 days (GC 3). The genotype, Konkan Safed (80.8 days) had highest lag period for pod formation, whereas, VCM 8 (5.95 days) had least lag period for pod formation.

4.1.20. Actual and effective seed growth periods

Actual and effective seed development and lag periods of cowpea genotypes are presented in Table 36. The differences among the genotypes were statistically significant for all the parameters.

Actual and effective seed growth periods (ASGP) in cowpea genotypes ranged between 17.25 (C 152) to 19.50 (Phule Pandhari) days. The effective seed growth periods (ESGP) amongst the genotype ranged between 10.09 (Konkan Safed) and 11.99 (GC 3) days. The genotype, Konkan Safed (9.32 days) had highest lag period for pod formation, whereas, VCM 8 (6.10 days) had least lag period for pod formation.

Table 36. Actual and effective seed growth periods among cowpea genotypes

Genotypes	Actual seed growth periods (ASGP), days	Effective seed growth periods (ESGP), days	Lag periods for seed growth (days)
VCM 8	17.50	11.40	6.10
Konkan Safed	19.25	10.09	9.16
Phule Pandhari	19.50	10.18	9.32
C 152	17.25	10.21	7.04
GC 3	19.25	11.99	7.26
Mean	18.55	11.40	7.15
SE _±	0.86	0.46	0.96
CD at 5%	NS	NS	NS

4.2. Characters of reproductive growth

The data in respect of phenological characters of cowpea genotypes were presented in Table 37. The differences among the genotypes were statistically significant for all the parameters and exhibited considerable amount of variation amongst the genotypes.

From the data in Table 34, it is revealed that the average crop duration of the crop from sowing to maturity was 78.40 days with maximum duration of 87.00 days in Konkan Safed and minimum of 69.00 days in VCM 8.

A critical perusal revealed that the average duration for the appearance of first flower bud in determinate type of variety (VCM 8) was 33.00 days, whereas, in other indeterminate types it was more than 41.00 days. This indicated that the transition from vegetative to reproductive phase in determinate early cowpea occurs in 33 days and in indeterminate types in 41 days. The average duration of the appearance of first flower bud and flower occurred in 42.10 and 43.05 days, respectively. Thus, from budding within next day anthesis of that bud takes place. The average duration for days to setting of first pod was 44.05 days. Thus after anthesis only one more day is required for setting of pods.

The average duration of first pod maturity was 62.60 days. Thus, the duration from appearance of first pod to first pod maturity was approximately 18 days. Had there been high degree of synchrony then the components of maturity period would have been remained as below.

Total maturity period	=	Days to first flower bud	+	Bud to flower anthesis	+	Duration for flowering to pod set	+	Pod set to Maturity
i.e. 63	=	42		+ 1		+ 2		+ 18

Thus if a hypothetical type of high synchrony is taken into consideration then the total maturity period can be finished into 63 days. However, the current investigation average maturity period was 78 days which was 15 days longer than the expected total period which could be due to indeterminate growth habit of cowpea genotypes under study.

4.2.1. Analysis of extending the duration of maturity than expectation

The critical perusal indicated that the appearance of flower bud from 42 days upto 62 days. Thus, there was a period of 20 days during which the buds continued to occurs in the plant. In consequence the flowering was also continued from 43 days from the appearance of first flower bud i.e. upto 63 days from sowing. In fact the day on which the first bud appears was the phase of commencement of reproductive phase.

In cowpea the vegetative growth like emergence and expansion of new branches, formation of new leaves which are the components of vegetative growth continue even after flowering phase. Thus, the reproductive and vegetative growth occurs simultaneously. Usually at the phase of maturity of first pod, the vegetative growth stops.

In current investigation, the first pod maturity occurred in 63rd days but the last flower bud appears on 62nd days. Thus, flowering continued till upto phase of first pod maturity. Thus, these appeared an intricate overlapping of occurrence of flower bud even at the time of first pod maturity which requires critical analysis.

4.2.2. Genotypic variation in component of maturity period

There was a significant variation in components of maturity period among all the five cowpea genotypes. It was revealed that, first flower bud appeared within 33 days in VCM 8 and required 41.00, 43.75, 44.00 and 48.75 days in GC 3, Konkan Safed, Phule Pandhari and C 152, respectively. Usually the transition into reproductive phase occurs within 41 to 49 days but VCM 8 has exceptionally shorter periods of vegetative phase due to its determinate growth habit. Similarly, first flower appeared within 42 to 49 days in GC 3, Konkan Safed, Phule Pandhari and C 152 but

in VCM 8 it requires 34 days. From the present investigation, it is evident that, pod setting in cowpea genotypes takes place with next day of the flower initiation. The period lies within the stages of floral bud initiation, initiation of flower and pod setting was only one day. The 50% flowering was achieved within 4 to 5 days after initiation of first flower in all the cowpea genotypes.

4.2.3. Last flower bud and last flower

There was wide range of variation for the duration to appearance of last flower bud. The last flower bud appeared within 50.50 days in VCM 8 followed by GC 3 (57.00 days), Phule Pandhari (63.00 days), Konkan Safed (68.25) and C 152 (70.75 days). The duration of opening of last flower was 51.00 days in VCM 8, 58.00 days in GC 3, 64.00 days in Phule Pandhari, 69.25 days in Konkan Safed and 71.75 days in C 152.

This clearly indicated that, there was a continuous staggered flowering for a period of about 34-38 days. This staggered flowering was one of the probable reasons for extending the duration than the expected one.

The duration of first pod set to first pod maturity was 19 days whereas last pod set to last pod maturity was only 15 days. Thus, there was a difference of 4 days in pod development period. Shortening of pod development period in late flowering stage was obviously due to enhancing rate of senescence. Thus, 4 days difference in pod maturity increases the complexity of understanding the maturity behavior of cowpea.

There was a considerable amount of variation for days to last pod set (52.00 to 72.25 days). Usually the last pod maturity also occurred in 74.00 to 87.00 days with an exception of VCM 8 (69.00 days). Four to five more days were required for overall maturity of the crop than physiological maturity.

Table 37. Characters of reproductive growth of cowpea genotypes

Genotypes	Days to initiation of floral bud	Days to initiation of first flower	Days to initiation of first pod	Days to last floral bud
VCM 8	33.00	34.00	35.00	50.50
Konkan Safed	43.75	44.75	45.75	68.25
Phule Pandhari	44.00	45.00	46.00	63.00
C 152	48.75	49.50	50.50	70.75
GC 3	41.00	42.00	43.00	57.00
Mean	42.10	43.05	44.05	61.90
SE _±	0.749	0.801	0.801	0.385
CD at 5%	2.307	2.468	2.468	1.185

Table 37. contd...

Genotypes	Days to last flower	Days to last pod formation	Days to first pod maturity	Days to Last pod maturity
VCM 8	51.00	52.00	52.50	69.00
Konkan Safed	69.25	70.25	65.00	87.00
Phule Pandhari	64.00	65.00	65.50	78.00
C 152	71.75	72.25	67.75	84.00
GC 3	58.00	59.00	62.25	74.00
Mean	62.80	63.70	62.60	78.40
SE _±	0.445	0.494	0.498	0.606
CD at 5%	1.371	1.521	1.534	1.866

From the above results a following summary can be drawn about the phenomena of flowering and maturity behavior of cowpea.

Maturity = First bud appearance (d) + Bud to first flower (d) + First flower to first pod set (d) + First pod set to first maturity (d) + Staggered flowering period (d) - Period of difference between last flower to first pod (d)
i. e. maturity period= (42 + 1 + 1 + 19 + 20) – 18 = 65 days.

4.3. Growth analysis

4.3.1. Dry matter production and it's assimilation in component parts of plant

4.3.1.1. Dry matter production in roots

The dry matter production in roots influenced by cowpea genotypes at various stages of growth are presented in Table 38. The differences among the genotypes were statistically significant at various stages of growth.

Table 38. Periodical dry matter production in roots as influenced by cowpea genotypes

Genotype \ DAS	Root dry matter production (g/ plant)			
	20	40	60	At harvest
VCM 8	0.195	2.968	7.568	9.833
Konkan Safed	0.540	4.150	19.618	20.275
Phule Pandhari	0.438	3.128	16.025	19.750
C 152	0.548	3.778	13.525	16.525
GC 3	0.365	2.520	13.633	14.448
Mean	0.417	3.309	14.074	16.166
SE _±	0.041	0.360	1.339	1.350
CD at 5%	0.127	1.111	4.128	4.161

The genotype, C 152 (0.548 g/ plant) recorded highest dry matter production in roots at 20 DAS followed by Konkan Safed (0.540 g/ plant) and Phule Pandhari (0.438 g/ plant). Afterwards, Konkan Safed maintained maximum dry matter accumulation at 40 DAS (4.150 g/ plant), 60 DAS (19.618 g/ plant) and at harvest (20.275 g/ plant). The genotype, VCM 8 recorded minimum dry matter accumulation at all the stages of growth.

4.3.1.2. Dry matter production in stem

The dry matter production in stem influenced by cowpea genotypes at various stages of growth are presented in Table 39.

The differences among the genotypes were statistically significant at various stages of growth.

The genotypes, Konkan Safed exhibited maximum and minimum dry matter accumulation in stem at 20 DAS (1.400 g/ plant), 40 DAS (24.340 g/ plant) and at harvest (99.550 g/ plant), however, at 60 DAS C 152 (35.030 g/ plant) recorded highest dry matter production in stem. The genotypes, Konkan Safed and C 152 were long duration varieties which utilized more periods for dry matter accumulation, therefore the dry matter in stem was higher at the time of maturity.

Table 39. Periodical dry matter production in stem as influenced by cowpea genotypes

Genotype \ DAS	Stem dry matter production (g/ plant)			
	20	40	60	At harvest
VCM 8	0.548	11.748	14.340	22.265
Konkan Safed	1.400	24.340	29.588	99.550
Phule Pandhari	0.880	13.698	33.850	59.750
C 152	0.988	15.920	35.030	61.250
GC 3	0.598	13.778	21.180	44.500
Mean	0.883	15.897	26.798	57.603
SE _±	0.099	1.218	2.659	3.844
CD at 5%	0.307	3.755	8.193	11.843

4.3.1.3. Dry matter production in leaves

The dry matter production in leaves influenced by cowpea genotypes at various stages of growth are presented in Table 40. The differences among the genotypes were statistically significant at various stages of growth.

The genotypes, Konkan Safed at 20 (3.200 g/ plant), 40 (32.448 g/ plant) and 60 DAS (27.233 g/ plant) and GC 3 at harvest (42.000 g/ plant) recorded maximum dry matter

accumulation in leaves. Whereas, GC at 20 DAS (1.390 g/ plant) and VCM 8 at 40 (14.035 g/ plant) and 60 DAS (10.773 g/ plant) and at harvest (19.000 g/ plant) recorded minimum dry matter accumulation in leaves. As an indeterminate growth habit of crop, the newly developed tender leaves were appeared at the time of maturity due to excess moisture in soil which has no relevance with crop yield, however, the dry matter was observed to be increased towards maturity in some varieties.

Table 40. Periodical dry matter production in leaves as influenced by cowpea genotypes

Genotype \ DAS	Leaves dry matter production (g/ plant)			
	20	40	60	At harvest
VCM 8	1.440	14.035	10.773	19.000
Konkan Safed	3.200	32.448	27.233	32.250
Phule Pandhari	1.885	18.390	24.348	24.500
C 152	2.215	22.033	21.873	20.000
GC 3	1.390	24.213	18.108	42.000
Mean	2.026	22.224	20.467	27.550
SE $\pm$	0.215	1.560	1.821	4.241
CD at 5%	0.664	4.809	5.613	13.069

4.3.1.4. Dry matter production in pods

The dry matter production in pods influenced by cowpea genotypes at various stages of growth are presented in Table 41. The differences among the genotypes were statistically significant at various stages of growth.

The genotype, VCM 8 (23.960 g/ plant) at 60 DAS and GC 3 (81.650 g/ plant) at harvest had highest dry matter accumulation in pods. Whereas, Konkan Safed (2.870 g/ plant) at 60 DAS and VCM 8 (26.325 g/ plant) had minimum dry matter accumulation in pods.

Table 41. Periodical dry matter production in pods as influenced by cowpea genotypes

Genotype \ DAS	Pods dry matter production (g/ plant)	
	60	At harvest
VCM 8	23.960	26.325
Konkan Safed	2.870	68.758
Phule Pandhari	7.387	70.555
C 152	5.497	73.955
GC 3	10.372	81.650
Mean	10.018	64.249
SE _±	1.471	3.404
CD at 5%	4.535	10.488

4.3.1.5. Total dry matter production

The total dry matter production influenced by cowpea genotypes at various stages of growth are presented in Table 42. The differences among the genotypes were statistically significant at various stages of growth.

Table 42. Periodical total dry matter production as influenced by cowpea genotypes

Genotype \ DAS	Total dry matter production (g/plant)			
	20	40	60	At harvest
VCM 8	2.183	28.751	56.641	77.423
Konkan Safed	5.140	60.938	79.309	221.533
Phule Pandhari	3.203	35.216	81.611	174.555
C 152	3.751	41.731	75.926	171.730
GC 3	2.353	40.511	63.294	182.598
Mean	3.326	41.429	41.429	165.568
SE _±	0.323	2.851	4.274	9.473
CD at 5%	0.998	8.786	13.169	1.4286

The genotypes, Konkan Safed at 20 (5.140 g/ plant), 40 DAS (60.938 g/ plant) and at harvest (221.533 g/ plant) and Phule Pandhari at harvest (81.611 g/ plant) recorded highest total matter

production. While, VCM 8 at 20 DAS (2.183 g/ plant), 40 DAS (14.035 g/ plant), 60 DAS (10.773 g/ plant) and at harvest (19.000 g/ plant) recorded minimum dry matter accumulation in leaves.

4.3.1.6. Per cent allocation of dry matter in component parts of plant

The data on per cent allocation of dry matter in component parts of plant of cowpea genotypes is presented in table No. 43. It is observed that, the highest percentage of dry matter was produced in leaves (61.00%) followed by stem (26.20%) and root (12.80%) at 20 DAS. The genotype, GC 3 (15.85%), Phule Pandhari (27.35%) and VCM 8 (65.98%) exhibited higher percentage of dry matter accumulation in root, stem and leaves, respectively. At 40 DAS, it followed same pattern i.e. leaves (53.33%) exhibited higher percentage dry matter accumulation followed by stem (38.42%) and root (8.25%). The genotype VCM 8 maintained higher per cent dry matter accumulation in root (10.18%) and stem (41.24%), whereas, GC 3 had higher per cent dry matter allocation in leaves (59.72%). At 60 DAS, per cent dry matter in stem, leaves, root and pods was to the tune of 36.63, 28.14, 19.52 and 15.70%, respectively. The highest per cent dry matter was diverted towards pod formation in VCM 8 (42.08%). In other genotypes, the vegetative growth was in progress. Therefore, the per cent allocation of dry matter in component parts was higher than VCM 8. At the time of harvest, the percent allocation of dry matter was higher in pods (38.32%) followed by stem (33.60%), leaves (17.42%) and root (10.66%). The genotype, VCM 8 recorded higher per cent dry matter in leaves (23.96%) and root (12.79%), Konkan Safed in stem (44.59%) and GC 3 in pods (44.75%).

Table 43. Per cent allocation of dry matter production (g/plant) in component parts of plant of cowpea genotypes

Genotypes	Root	Stem	Leaves	Pods
20 DAS				
VCM 8	9.05	25.04	65.91	--
Konkan Safed	10.66	27.24	62.10	--
Phule Pandhari	14.05	27.35	58.60	--
C 152	14.39	26.19	59.42	--
GC 3	15.85	25.20	58.95	--
Mean	12.80	26.20	61.00	
40 DAS				
VCM 8	10.18	41.24	48.58	--
Konkan Safed	6.77	39.80	53.43	--
Phule Pandhari	9.05	38.82	52.13	--
C 152	9.06	38.13	52.81	--
GC 3	6.20	34.08	59.72	--
Mean	8.25	38.42	53.33	
60 DAS				
VCM 8	13.48	25.50	18.97	42.05
Konkan Safed	24.79	37.20	34.38	3.63
Phule Pandhari	19.71	41.33	29.98	8.98
C 152	18.12	45.92	28.64	7.32
GC 3	21.52	33.22	28.74	16.52
Mean	19.52	36.63	28.14	15.70
Maturity				
VCM 8	12.79	29.38	23.96	33.87
Konkan Safed	10.58	44.59	14.35	30.52
Phule Pandhari	11.34	34.45	13.75	40.46
C 152	10.69	35.14	12.17	42.00
GC 3	7.90	24.46	22.89	44.75
Mean	10.66	33.60	17.42	38.32

4.3.2. Growth Parameters

The growth analysis technique includes the studies on absolute growth rate (AGR), relative growth rate (RGR), net assimilation rate (NAR), leaf area ratio (LAR), leaf area index (LAI), specific leaf weight (SLW) and leaf area duration (LAD). The results on above aspects were depicted as below.

4.3.2.1. Absolute growth rate (AGR)

The absolute growth rate (AGR) influenced by cowpea genotypes at various stages of growth are presented in Table 44. The differences among the genotypes were statistically significant at various stages of growth.

Table 44: Periodical absolute growth rate (AGR) as influenced by cowpea genotypes

Genotype \ DAS	Absolute growth rate (g/day/plant)			
	0-20	21-40	41-60	61-harvest
VCM 8	0.1091	1.3284	1.3945	2.3092
Konkan Safed	0.2570	2.7899	0.9185	5.4028
Phule Pandhari	0.1601	1.6006	2.3198	5.1636
C 152	0.1875	1.8990	1.7098	3.5763
GC 3	0.1176	1.9079	1.1391	8.5218
Mean	0.1663	1.9052	1.4963	4.9947
SE _±	0.0162	0.1476	0.2521	0.5213
CD at 5%	0.0499	0.4549	0.7767	1.6062

The genotypes, Konkan Safed exhibited maximum AGR between 0-20 (0.2570 g/ day/ plant) and 21-40 DAS (2.7899 g/ day/ plant), whereas, VCM 8 had minimum AGR between 0-20 (0.1091 g/ day/ plant) and 21-40 DAS (1.3284 g/ day/ plant). At 41-60 DAS, Phule Pandhari (2.3198 g/ day/ plant) and Konkan Safed (0.9185 g/ day/ plant) recorded highest and lowest AGR, respectively. From 61 DAS-harvest, GC 3 (8.5218 g/ day/ plant)

recorded significantly highest AGR followed by Konkan Safed (5.4028 g/ day/ plant) and Phule Pandhari g/ day/ plant) over VCM 8 (2.3092 g/ day/ plant) and C 152 (3.5763 g/ day/ plant).

4.3.2.2. Relative growth rate (RGR)

The relative growth rate (RGR) influenced by cowpea genotypes at various stages of growth are presented in Table 45. The differences among the genotypes were statistically significant between 40-60 DAS and 60 DAS - harvest.

The genotypes, GC 3 between 20-40 DAS (0.0621 g/g/day) and 61 DAS-harvest (0.0332 g/g/day) and Phule Pandhari between 41-60 DAS (0.0185 g/g/day) exhibited higher RGR. However, Phule Pandhari (0.0522 g/g/day) between 20-40 DAS, Konkan Safed (0.0050 g/g/day) between 41-60 DAS and C 152 (0.0136 g/g/day) had minimum RGR.

Table 45. Periodical relative growth rate (RGR) as influenced by cowpea genotypes

Genotype \ DAS	Relative growth rate (g/g/day)		
	20-40	41-60	61 - harvest
VCM 8	0.0559	0.0146	0.0152
Konkan Safed	0.0539	0.0050	0.0168
Phule Pandhari	0.0520	0.0185	0.0183
C 152	0.0522	0.0115	0.0136
GC 3	0.0621	0.0056	0.0332
Mean	0.0552	0.0110	0.0194
SE _±	0.0025	0.0020	0.0022
CD at 5%	NS	0.0063	0.0069

4.3.2.3. Net assimilation rate (NAR)

The net assimilation rate (NAR) influenced by cowpea genotypes at various stages of growth are presented in Table 46.

The differences among the genotypes were statistically significant at various stages of growth.

The genotypes, VCM 8 maintained highest NAR between 20-40 DAS (3.8085 g/dm²/leaflet/day) and 41-60 DAS (2.3553 g/dm²/leaflet/day), whereas, Konkan Safed (6.4372 g/dm²/leaflet/day) maintained highest NAR between 61 DAS to harvest. However, it is interesting to note that, the genotype, Konkan Safed between 20-40 DAS (2.3599 g/dm²/leaflet/day) and 41-60 DAS (0.3061 g/dm²/leaflet/day) and VCM 8 between 61 DAS-harvest (1.3457 g/dm²/leaflet/day) were found to be inferior for NAR.

Table 46. Periodical net assimilation rate (NAR) as influenced by cowpea genotypes

Genotype \ DAS	Net assimilation rate (g/dm ² /leaflet/day)		
	20-40	41-60	61 - harvest
VCM 8	3.8085	2.3553	1.3457
Konkan Safed	2.3599	0.3061	6.4372
Phule Pandhari	2.7210	1.3581	2.7050
C 152	2.9398	1.0421	4.5402
GC 3	3.4116	0.4466	4.1758
Mean	3.0482	1.1016	3.8408
SE+	0.2313	0.5918	0.4636
CD at 5%	0.7126	0.8298	1.4286

4.3.2.4. Leaf area index (LAI)

The leaf area index (LAI) influenced by cowpea genotypes at various stages of growth are presented in Table 47. The differences among the genotypes were statistically significant at various stages of growth.

The genotypes, Konkan Safed at 20 (1.36), 40 (20.08) and 60 DAS (11.55) and Phule Pandhari at harvest maintained higher LAI.

Whereas, VCM 8 at 20 DAS (0.49), 40 DAS (5.46), 60 DAS (1.98) and at harvest (2.04) recorded minimum LAI.

Table 47. Periodical leaf area index (LAI) as influenced by cowpea genotypes

Genotype \ DAS	Leaf area index			
	20	40	60	At harvest
VCM 8	0.49	5.46	1.98	2.04
Konkan Safed	1.36	20.08	11.55	6.63
Phule Pandhari	0.71	9.53	10.50	7.52
C 152	1.09	8.93	7.59	5.65
GC 3	0.67	9.43	7.86	4.23
Mean	0.86	10.69	7.90	5.21
SE _±	0.033	1.500	0.334	0.153
CD at 5%	0.101	4.622	1.031	0.472

4.3.2.5. Leaf area ratio (LAR)

The leaf area ratio (LAR) influenced by cowpea genotypes at various stages of growth are presented in Table 48. The differences among the genotypes were statistically significant at various stages of growth.

Table 48. Periodical leaf area ratio (LAR) as influenced by cowpea genotypes

Genotype \ DAS	Leaf area ratio (dm ² / g)		
	20-40	41-60	61 - harvest
VCM 8	0.0148	0.0062	0.0113
Konkan Safed	0.0230	0.0168	0.0026
Phule Pandhari	0.0193	0.0137	0.0068
C 152	0.0180	0.0114	0.0031
GC 3	0.0186	0.0139	0.0080
Mean	0.0187	0.0124	0.0063
SE ₊	0.0712	0.0149	0.0073
CD at 5%	0.0998	0.0460	0.0227

The genotypes, Konkan Safed between 20-40 DAS (0.0230 dm²/ g) and 41-60 DAS (0.0168 dm²/g) and VCM 8 between 61 DAS-harvest (0.0113 dm²/g) maintained highest LAR. Whereas, VCM 8 between 20-40 DAS (0.0148 dm²/g) and 41-60 DAS (0.0062 dm²/ g) and Konkan Safed VCM 8 between 61 DAS-harvest (0.0026 dm²/ g) were found to be inferior for LAR.

4.3.2.6. Specific leaf area (SLA)

The specific leaf area (SLA) influenced by cowpea genotypes at various stages of growth are presented in Table 49. The differences among the genotypes were statistically significant at various stages of growth.

Table 49. Periodical specific leaf area (SLA) as influenced by cowpea genotypes

Genotype \ DAS	Specific leaf area (dm ² /g)			
	20	40	60	At harvest
VCM 8	10.16	11.58	5.87	0.80
Konkan Safed	12.97	18.38	12.82	0.88
Phule Pandhari	11.67	15.76	13.07	1.31
C 152	14.94	12.37	10.76	1.08
GC 3	14.81	11.83	13.23	0.70
Mean	12.91	13.98	11.15	0.95
SE+	1.024	1.462	1.048	0.081
CD at 5%	3.157	4.507	3.231	0.249

The genotypes, C 152 (14.94 dm²/ g) and GC 3 (14.81 dm²/g) showed significantly higher SLW over VCM 8 (10.16 dm²/ g) at 20 DAS. However, at 40 DAS, Konkan Safed (18.38 dm²/ g) was significantly superior over VCM 8 (11.58 dm²/ g), GC 3 (11.83 dm²/ g) and C 152 (12.37 dm²/ g). At 60 DAS, GC 3 (13.23 dm²/ g) and Phule Pandhari (13.07 dm²/ g) were significantly superior over VCM 8 (5.87 dm²/ g) and at par with Konkan Safed (12.82 dm²/ g) and C 152 (1076 dm²/ g). At harvest, Phule Pandhari (1.31 dm²/ g) and C

152 (1.08 dm²/ g) maintained significantly higher SLW, while, Konkan Safed (0.88 dm²/ g), VCM 8 (0.80 dm²/ g) and GC 3(0.70 dm²/ g) were at par with each other.

4.3.2.7. Leaf area duration (LAD)

The leaf area duration (LAD) influenced by cowpea genotypes at various stages of growth are presented in Table 50. The differences among the genotypes were statistically significant at various stages of growth.

Konkan Safed was significantly superior for leaf area duration over all the genotypes between 20-40 (64.32 days), 41-60 (94.90 days) and 61 DAS-harvest (73.61 days). The genotype, VCM 8 had minimum LAD between 20-40 (17.84 days), 41-60 (22.33 days) and 61 DAS-harvest (5.42 days). VCM was short duration variety in which the higher number of leaves was developed in short period at the time of maturity due to excess moisture therefore, it recorded minimum LAD.

Table 50. Periodical leaf area duration (LAD) as influenced by cowpea genotypes

DAS Genotype	Leaf area duration		
	20-40	41-60	61 - harvest
VCM 8	17.84	22.33	5.42
Konkan Safed	64.32	94.90	73.61
Phule Pandhari	30.72	60.08	48.65
C 152	30.06	49.55	47.65
GC 3	30.32	51.87	25.39
Mean	34.65	55.75	40.14
SE+	4.52	4.40	1.03
CD at 5%	13.92	13.57	3.71

4.3.3. Physiological Parameters

4.3.3.1. Rate of photosynthesis

The rate of photosynthesis influenced by cowpea genotypes at various stages of growth are presented in Table 51. The differences among the genotypes were statistically significant at all the stages of growth.

The rate of photosynthesis was significantly higher in Konkan Safed ($19.1 \mu\text{mol m}^{-2} \text{sec}^{-1}$) and Phule Pandhari ($18.08 \mu\text{mol m}^{-2} \text{sec}^{-1}$) over VCM 8 ($15.1 \mu\text{mol m}^{-2} \text{sec}^{-1}$) and C 152 ($15.9 \mu\text{mol m}^{-2} \text{sec}^{-1}$) at 20 DAS. The higher rate of photosynthesis was found in C 152 ($25.1 \mu\text{mol m}^{-2} \text{sec}^{-1}$) and lower in GC 3 ($20.8 \mu\text{mol m}^{-2} \text{sec}^{-1}$) at 40 DAS. At 60 DAS, Konkan Safed ($26.8 \mu\text{mol m}^{-2} \text{sec}^{-1}$) and C 152 ($26.3 \mu\text{mol m}^{-2} \text{sec}^{-1}$) recorded significantly higher rate of photosynthesis over VCM 8 ($15.9 \mu\text{mol m}^{-2} \text{sec}^{-1}$). At maturity, C 152 ($14.3 \mu\text{mol m}^{-2} \text{sec}^{-1}$) and Konkan Safed ($13.8 \mu\text{mol m}^{-2} \text{sec}^{-1}$) had significantly higher rate of photosynthesis over GC 3 ($11.5 \mu\text{mol m}^{-2} \text{sec}^{-1}$) and VCM 8 ($10.4 \mu\text{mol m}^{-2} \text{sec}^{-1}$).

Table 51. Periodical rate of photosynthesis (P_n) as influenced by cowpea genotypes

Genotype \ DAS	Rate of photosynthesis ($\mu\text{mol m}^{-2} \text{sec}^{-1}$)			
	20	40	60	At maturity
VCM 8	15.1	21.6	15.9	10.4
Konkan Safed	19.1	23.6	26.8	13.8
Phule Pandhari	18.1	22.1	21.4	12.9
C 152	15.9	25.1	26.3	14.3
GC 3	17.1	20.8	20.2	11.5
Mean	17.0	22.6	22.1	12.4
SE+	0.83	0.67	3.10	0.57
CD at 5%	2.55	2.06	9.52	1.70

4.3.3.2. Rate of transpiration

The rate of transpiration influenced by cowpea genotypes at various stages of growth are presented in Table 52. The differences among the genotypes were statistically significant at 40 and 60 DAS.

The genotype, Konkan Safed ($3.44 \text{ mmol m}^{-2} \text{ sec}^{-1}$) was significantly superior for rate of transpiration over C 152 ($2.73 \text{ mmol m}^{-2} \text{ sec}^{-1}$), GC 3 ($2.87 \text{ mmol m}^{-2} \text{ sec}^{-1}$) and VCM 8 ($3.01 \text{ mmol m}^{-2} \text{ sec}^{-1}$) and at par with Phule Pandhari ($3.13 \text{ mmol m}^{-2} \text{ sec}^{-1}$) at 20 DAS. The higher rate of transpiration was found in GC 3 ($4.19 \text{ mmol m}^{-2} \text{ sec}^{-1}$) and lower in VCM 8 ($3.89 \text{ mmol m}^{-2} \text{ sec}^{-1}$) at 40 DAS. At 60 DAS, Konkan Safed ($3.42 \text{ mmol m}^{-2} \text{ sec}^{-1}$) had higher rate of transpiration followed by C 152 ($3.18 \text{ mmol m}^{-2} \text{ sec}^{-1}$) and Phule Pandhari ($3.03 \text{ mmol m}^{-2} \text{ sec}^{-1}$). At maturity, Konkan Safed ($1.90 \text{ mmol m}^{-2} \text{ sec}^{-1}$) and Phule Pandhari ($1.81 \text{ mmol m}^{-2} \text{ sec}^{-1}$) were found to be superior, whereas, GC 3 ($1.78 \text{ mmol m}^{-2} \text{ sec}^{-1}$) and VCM 8 ($1.75 \text{ mmol m}^{-2} \text{ sec}^{-1}$) were inferior for rate of transpiration.

Table 52. Periodical rate of transpiration as influenced by cowpea genotypes

Genotype \ DAS	Rate of transpiration ($\text{mmol m}^{-2} \text{ sec}^{-1}$)			
	20	40	60	At maturity
VCM 8	3.01	3.89	2.20	1.75
Konkan Safed	3.44	3.90	3.42	1.90
Phule Pandhari	3.13	4.11	3.03	1.81
C 152	2.73	4.05	3.18	1.79
GC 3	2.87	4.19	2.25	1.78
Mean	3.03	4.03	2.81	1.81
SE+	0.016	0.015	0.023	0.011
CD at 5%	0.49	NS	0.070	NS

4.3.3.3. Water use efficiency (WUE)

The water use efficiency influenced by cowpea genotypes at various stages of growth are presented in Table 53. The treatment differences among the genotypes were statistically non-significant at various stages of growth.

The genotype, GC3 at 20 (5.99) and 60 DAS (9.02) and C 152 at 40 DAS (6.25 and at maturity (8.78) recorded higher WUE. VCM 8 at 20 DAS (5.02) and at maturity (7.43), GC 3 at 40 DAS (5.04) and Phule Pandhari at 60 DAS (7.29) recorded minimum WUE.

Table 53. Periodical water use efficiency (WUE) as influenced by cowpea genotypes

Genotype \ DAS	Water use efficiency			
	20	40	60	At maturity
VCM 8	5.02	5.57	7.35	5.94
Konkan Safed	5.60	6.05	7.85	7.26
Phule Pandhari	5.77	5.37	7.29	7.13
C 152	5.81	6.25	8.33	7.43
GC 3	5.99	5.04	9.02	6.46
Mean	5.64	5.65	7.97	6.84
SE _±	0.064	0.084	0.73	0.23
CD at 5%	NS	NS	NS	NS

4.3.3.4. Stomatal conductance

The stomatal conductance influenced by cowpea genotypes at various stages of growth are presented in Table 54. The differences among the genotypes were statistically significant at various stages of growth except at 20 DAS.

The genotype, Konkan Safed ($0.437 \mu\text{mol m}^{-2} \text{ sec}^{-1}$) and Phule Pandhari ($0.418 \mu\text{mol m}^{-2} \text{ sec}^{-1}$) had higher stomatal conductance as against lower in GC 3 ($0.353 \mu\text{mol m}^{-2} \text{ sec}^{-1}$) and C 152 ($0.356 \mu\text{mol m}^{-2} \text{ sec}^{-1}$) at 20 DAS. At 40 DAS, Konkan Safed ($0.632 \mu\text{mol m}^{-2} \text{ sec}^{-1}$)

m⁻² sec⁻¹) and VCM 8 (0.620 $\mu\text{mol m}^{-2} \text{sec}^{-1}$) recorded maximum stomatal conductance. At 60 DAS, C 152 (0.245 $\mu\text{mol m}^{-2} \text{sec}^{-1}$) and GC 3 (0.316 $\mu\text{mol m}^{-2} \text{sec}^{-1}$) showed least stomatal conductance whereas, VCM 8 (0.399 $\mu\text{mol m}^{-2} \text{sec}^{-1}$) showed highest stomatal conductance. At maturity, stomatal conductance ranged between 0.183 (Phule Pandhari) and 0.273 $\mu\text{mol m}^{-2} \text{sec}^{-1}$ (VCM 8).

Table 54. Periodical stomatal conductance as influenced by cowpea genotypes

Genotype \ DAS	Stomatal conductance ($\mu\text{mol m}^{-2} \text{sec}^{-1}$)			
	20	40	60	At maturity
VCM 8	0.376	0.620	0.399	0.273
Konkan Safed	0.437	0.632	0.378	0.184
Phule Pandhari	0.418	0.356	0.347	0.183
C 152	0.356	0.300	0.245	0.188
GC 3	0.353	0.501	0.316	0.239
Mean	0.388	0.482	0.337	0.213
SE _±	0.0005	0.0005	0.0002	0.0008
CD at 5%	NS	0.0016	0.0005	0.0025

4.4. Morphological characters

4.4.1. Vegetative growth and source

The vegetative phase governs the overall phenotypic expression of the plant and prepares the plant for next important reproductive phase. The root, stem, branches and leaves, all these parts constitute vegetative phase and perform specific functions.

4.4.1.1. Plant height

The plant height influenced by cowpea genotypes at various stages of growth are presented in Table 55. The differences among the genotypes were statistically significant at various stages of growth.

The genotype, Phule Pandhari (14.24 cm) and C 152 (13.04 cm) were significantly taller than VCM 8 (10.56 cm) and Konkan Safed (11.31 cm) at 20 DAS. At 40 DAS, Konkan Safed (85.17 cm) achieved maximum plant height followed by Phule Pandhari (71.09 cm) and C 152 (63.84 cm) which were significantly superior over VCM 8 (25.85 cm) and GC 3 (35.15 cm). At 40 and 60 DAS, C 152 (99.75 cm), Konkan Safed (94.67 cm) and Phule Pandhari (89.42) were grown faster and achieved significantly higher plant height over VCM 8 (30.48 cm) and GC 3 (66.92 cm). At harvest, Phule Pandhari (118.35 cm), C 152 (105.75) and Konkan safed (98.95) maintained highest plant height over VCM 8 (35.05 cm) and GC 3 (69.25 cm).

Table 55. Periodical plant height as influenced by cowpea genotypes

Genotype \ DAS	Plant height (cm)			
	20	40	60	At harvest
VCM 8	10.56	25.85	30.88	35.05
Konkan Safed	11.31	85.17	94.67	98.95
Phule Pandhari	14.24	71.09	89.42	118.35
C 152	13.04	63.84	99.75	105.75
GC 3	11.72	35.15	66.92	69.25
Mean	12.17	56.22	74.33	85.47
SE _±	0.557	5.271	3.095	2.504
CD at 5%	1.716	16.242	9.537	7.715

4.4.1.2. Number of branches/ plant

The number of branches/ plant influenced by cowpea genotypes at various stages of growth is presented in Table 56. The differences among the genotypes were statistically significant at 40 DAS and at harvest.

The genotype, Phule Pandhari (2.25), Konkan Safed (2.17) and C 152 (2.08) recorded higher number of branches per plant at 20

DAS. At 40 DAS, the determinate growth habit genotype VCM 8 (6.08) produced maximum number of branches followed by Konkan Safed (4.08) and GC 3 (3.75). The genotypes, Phule Pandhari and C 152 (8.50) maintained higher number of branches per plant followed by GC 3 (8.09) and Konkan Safed (8.08) at 60 DAS. At harvest, Phule Pandhari (9.90) and C 152 (9.40) exhibited significantly higher number of branches per plant over Konkan Safed (8.40), GC 3 (8.30) and VCM 8 (8.05).

Table 56. Periodical number of branches/ plant as influenced by cowpea genotypes

Genotype \ DAS	Number of branches/ plant			
	20	40	60	At harvest
VCM 8	2.00	6.08	7.42	8.05
Konkan Safed	2.17	4.08	8.08	8.40
Phule Pandhari	2.25	2.67	8.50	9.90
C 152	2.08	3.50	8.50	9.40
GC 3	2.00	3.75	8.09	8.30
Mean	2.10	4.02	8.12	8.81
SE _±	0.121	0.292	0.451	0.235
CD at 5%	NS	0.899	NS	0.724

4.4.1.3. Number of leaves/ plant

The number of leaves/ plant influenced by cowpea genotypes at various stages of growth is presented in Table 57. The differences among the genotypes were statistically significant at various stages of growth except at 40 DAS.

The genotype, Konkan Safed (16.75) was significantly superior for number of leaves per plant at 20 DAS over GC 3 (12.08), VCM 8 (13.25), C 152 (13.75) and Phule Pandhari (14.00). At 40 DAS, Konkan safed (86.75) produced maximum number of leaves per plant followed by GC 32 (71.58) and VCM 8 (62.25). The genotype, Konkan safed (96.75) was significantly superior for number of

leaves/ plant over entire genotypes at 60 DAS. Phule Pandhari (81.33), GC 3 (79.00) and C 152 (76.25) were significantly superior over VCM 8 (31.67). At harvest, Phule Pandhari (58.30), C 152 (56.75) and Konkan Safed (55.50) maintained significantly higher number of leaves per plant.

Table 57. Periodical number of leaves/ plant as influenced by cowpea genotypes

Genotype \ DAS	Number of leaves/ plant			
	20	40	60	At harvest
VCM 8	13.25	62.25	31.67	32.55
Konkan Safed	16.75	86.75	96.75	55.50
Phule Pandhari	14.00	60.00	81.33	58.30
C 152	13.75	59.25	76.25	56.75
GC 3	12.08	71.58	79.00	42.55
Mean	13.97	67.97	73.00	49.13
SE _±	0.235	8.493	2.973	1.599
CD at 5%	0.723	NS	9.161	4.928

4.4.1.4. Leaf area/ plant

The leaf area/ plant influenced by cowpea genotypes at various stages of growth are presented in Table 58. The differences among the genotypes were statistically significant at various stages of growth.

The genotype, Konkan Safed (40.66 dm²) was significantly superior for leaf area per plant at 20 DAS over VCM 8 (14.59 dm²), GC 3 (20.23 dm²), Phule Pandhari (21.28 dm²) and C 152 (32.71). At 40 DAS, Konkan safed (602.51 dm²) maintained maximum leaf area per plant followed by Phule Pandhari (285.93 dm²) and GC 3 (282.95 dm²). The genotype, Konkan safed (346.47 dm²) was significantly superior for leaf area/ plant over entire genotypes at 60 DAS. Phule Pandhari (314.86 dm²), GC 3 (235.72 dm²) and C 152 (227.64 dm²) were significantly superior over VCM 8 (59.45

dm²). At harvest, Phule Pandhari (225.69 dm²) recorded significantly highest leaf area per plant followed by Konkan Safed (198.75 dm²) and C 152 (169.42 dm²).

Table 58. Periodical leaf area/ plant as influenced by cowpea genotypes

Genotype \ DAS	Leaf area/ plant (dm ²)			
	20	40	60	At harvest
VCM 8	14.59	163.86	59.45	61.11
Konkan Safed	40.66	602.51	346.47	198.75
Phule Pandhari	21.28	285.93	314.86	225.69
C 152	32.71	267.88	227.64	169.42
GC 3	20.23	282.95	235.72	126.96
Mean	25.89	320.63	236.83	156.39
SE _±	0.954	45.036	10.031	4.609
CD at 5%	2.939	138.76	30.904	14.202

4.4.2. Generative Growth and Sink Capacity

The functional significance of the morpho-physiological and biochemical characteristics and growth phases of reproductive organs notably their relationships with yield and its components. Furthermore, it is to be noted that the studies on yield contributing characters considered being worthy to improve the yield of crop. Therefore, the results on the traits related to crop productivity i.e. number of pods/plant, seeds/pod/ seeds/plant, seed yield/plant, 100 seed weight, fodder yield, total biological yield and harvest index are presented in Table 59. It is evident that, the treatment differences were statistically significant for all the characters except for seeds/ pod indicating that there was wide range of variation for all the characters.

4.4.2.1. Number of pods/plant

The higher number of pods per plant was recorded by the genotype C 152 (15.95) followed by GC 3 (15.40), Konkan Safed (15.10), Phule Pandhari (14.05) which were significantly superior over VCM 8 (13.35).

4.4.2.2. Seeds/pod

The treatment differences were non-significant indicating that there was a narrow range of variation amongst the genotypes. The genotype C 152 (11.99) maintained higher number of seeds/ pod followed by Phule Pandhari (11.71), GC 3 (11.50), Konkan Safed (11.30) and VCM 8 (11.25).

4.4.2.3. Seeds/plant

The genotype C 152 (192.52) maintained higher number of seeds/plant which was significantly superior over VCM 8 (150.20) and Phule Pandhari (164.09). GC 3 (176.66) and Konkan Safed (171.33) were at par with C 152.

4.4.2.4. Seed yield/plant

The genotype C 152 (15.25 g) was significantly superior for seed yield per plant over all the genotypes. Other genotypes i.e. GC 3 (12.28 g), Phule Pandhari (11.65 g), Konkan safed (11.02 g) and VCM 8 (10.17 g) were at par with each other.

4.4.2.5. 100 seed weight

The genotype Konkan Safed (10.20 g/ 100 seed) showed bold seed size followed by GC 3 (9.21 g/ 100 seed), VCM 8 (9.02/ 100 seed), C 152 (8.75 g/100 seed) and Phule Pandhari (8.40 g/ 100 seed).

4.4.2.6. Seed Yield/plot (kg)

The genotype C 152 (1.376 kg) was significantly superior for seed yield per plot over all the genotypes except Phule Pandhari (1.204 kg). Konkan Safed (1.039 kg), GC 3 (1.035 kg) and VCM 8 (0.992 kg) were at par with each other for seed yield/ plot.

Table 59. Generative growth and sink capacity of cowpea genotypes

Genotypes	Pods/plant	Seeds/ Pod	Seeds/ plant	100 grain weight (g)	Yield/ plant (g)
VCM 8	13.35	11.25	150.20	9.02	10.17
Konkan Safed	15.10	11.30	171.33	10.20	11.02
Phule Pandhari	14.05	11.71	164.09	8.40	11.65
C 152	15.95	11.99	192.52	8.75	15.25
GC 3	15.40	11.50	176.66	9.21	12.28
Mean	14.77	11.55	170.96	9.12	12.07
SE _±	0.537	0.224	8.583	0.031	0.700
CD at 5%	1.654	NS	26.446	0.094	2.157

Table 59. Contd...

Genotypes	Seed yield (kg/plot)	Seed yield (kg/ha)	Fodder yield (kg/plot)	Biological yield (kg/ plot)	Harvest index (%)
VCM 8	0.992	918.36	1.413	2.405	41.25
Konkan Safed	1.039	961.65	2.133	3.172	32.74
Phule Pandhari	1.204	1114.67	2.135	3.339	36.05
C 152	1.376	1273.94	2.211	3.586	38.36
GC 3	1.035	958.41	0.936	1.971	52.52
Mean	1.129	1045.41	1.766	2.895	40.18
SE _±	0.056	49.552	0.087	0.139	0.0021
CD at 5%	0.173	152.674	0.269	0.429	0.0063

4.4.2.7. Seed yield (kg/ha)

The genotype C 152 (1273.94 kg/ ha) was significantly superior for seed yield per ha over all the genotypes. Phule Pandhari (1114.67kg) also exhibited significantly higher performance for seed yield per ha over Konkan Safed (961.65 kg/ ha), GC 3 (958.41 kg/ ha) and VCM 8 (918.36 kg/ ha).

4.4.2.8. Fodder yield/plot (kg)

The genotypes, C 152 (2.211 kg), Phule Pandhari (2.135 kg) and Konkan Safed (2.133 kg) yielded significantly higher fodder yield per plot over GC 3 (0.936 kg) and VCM 8 (1.413 kg).

4.4.2.9. Total biological yield/plot (kg)

The genotypes, C 152 (3.586 kg), Phule Pandhari (3.339 kg) and Konkan Safed (3.172 kg) yielded significantly higher biological yield per plot over GC 3 (0.936 kg) and VCM 8 (1.413 kg).

4.4.2.10. Harvest index

The genotype, GC 3 (52.52%) recorded highest harvest index followed by VCM 8 (41.25%), C 152 (38.36%), Phule Pandhari (36.05%) and Konkan Safed (32.74%).

4.5. Bio-chemical parameters.

4.5.1. Crude protein

The crude protein in seeds influenced by cowpea genotypes at various stages of growth are presented in Table 60. The differences among the genotypes for crude protein in seeds were statistically significant at 9 and 12 DAF.

In the present investigation, crude protein of seeds was relatively low at 9 DAF, however, it increased rapidly at 12 DAF and achieved maximum crude protein at 15 DAF. Thereafter it remains constant with the advancement of the seed growth. At 9 DAF,

protein content amongst genotypes ranged between 9.98 (C 152) and 17.83 (VCM 8) per cent. At 12 DAF, VCM 8 (21.19%) recorded higher crude protein followed by Konkan Safed (20.81%) and C 152 (18.38%). The genotype Konkan Safed maintained numerically higher levels of crude protein at 15 DAF (22.67%) and GC 3 at 18 (23.27%) and 21 DAF (24.48%).

Table 60. Periodical crude protein content as influenced by cowpea genotypes

DAF Genotype	Protein content (%)				
	9	12	15	18	21
VCM 8	17.83	21.19 (18.84)	22.27 (24.90)	22.30 (25.07)	23.07 (29.39)
Konkan Safed	15.23	20.81 (36.64)	22.67 (48.85)	22.71 (49.11)	23.39 (53.58)
Phule Pandhari	14.43	18.30 (26.82)	22.10 (53.15)	22.40 (55.23)	22.63 (56.83)
C 152	9.98	18.38 (84.17)	22.36 (124.05)	22.68 (127.25)	23.09 (131.36)
GC 3	13.18	16.97 (28.76)	20.43 (55.01)	23.27 (76.56)	24.48 (85.74)
Mean	14.13	19.13 35.39	21.96 55.41	22.67 60.44	23.33 65.11
SE $\pm$	0.14	0.37	0.35	1.16	0.36
CD at 5%	0.42	1.14	NS	NS	NS

Figures in parentheses indicate percent increase over initial stage of seed growth.

4.5.2. Carbohydrates

4.5.2.1. Reducing sugars

The reducing sugars in seeds influenced by cowpea genotypes at various stages of growth are presented in Table 61. The differences among the genotypes for reducing sugars in seeds were statistically significant only at 9, 12 and 15 DAF.

The reducing sugars increased with advanced stages of seed growth in all the genotypes. At 9 DAF, reducing sugars amongst genotypes ranged between 0.54% (C 152) and 2.63% (VCM 8). At 12 DAF, VCM (4.60%) had higher reducing sugars followed by Konkan

Safed (4.22%) and C 152 (3.24%). The genotype Konkan Safed at 15 (5.00%) and GC 3 at 18 (5.38%) and 21 DAF (5.92%) maintained higher percentage of reducing sugars.

Table 61. Periodical reducing sugars as influenced by cowpea genotypes

Genotype \ DAF	Reducing sugars (%)				
	9	12	15	18	21
VCM 8	2.63	4.60 (74.90)	4.90 (86.31)	4.80 (82.51)	5.25 (99.62)
Konkan Safed	1.56	4.22 (170.51)	5.00 (220.51)	5.04 (223.08)	5.08 (225.64)
Phule Pandhari	1.37	2.57 (87.59)	4.56 (232.85)	4.87 (255.47)	4.72 (244.53)
C 152	0.54	3.24 (500.00)	4.90 (807.41)	5.12 (848.15)	5.27 (875.93)
GC 3	0.83	1.46 (75.90)	4.20 (406.02)	5.38 (548.19)	5.92 (613.25)
Mean	1.39	3.22 (131.65)	4.71 (238.85)	5.04 (262.59)	5.24 (276.98)
SE+	0.205	0.053	0.048	0.024	0.077
CD at 5%	0.632	0.163	0.148	NS	NS

Figures in parentheses indicate percent increase over initial stage of seed growth.

4.5.2.2. Total carbohydrates

The carbohydrate content in seeds influenced by cowpea genotypes at various stages of growth are presented in Table 62. The differences among the genotypes for carbohydrate content in seeds were statistically non-significant at various stages of growth.

In the present investigation, the carbohydrate content increased steadily with the advancement of the seed growth. At 9 DAF, carbohydrate content amongst genotypes ranged between 54.79 (Konkan Safed) and 59.65% (C 152). At 12 DAF, C 152 (60.04%) had higher carbohydrate content followed by VCM 8 (56.42%) and Konkan Safed (55.74%). The genotype C 152 maintained higher percentage of carbohydrate content at 15 (60.98%), 18 (62.24) and 21 DAF (62.42%).

Table 62. Periodical carbohydrate content as influenced by cowpea genotypes

Genotype \ DAF	Carbohydrate content (%)				
	9	12	15	18	21
VCM 8	55.24	56.42 (2.14)	59.24 (7.24)	59.10 (6.99)	58.93 (6.68)
Konkan Safed	54.79	55.74 (1.73)	59.40 (8.41)	59.94 (9.40)	62.25 (13.62)
Phule Pandhari	55.69	55.86 (0.31)	59.73 (7.25)	61.61 (10.63)	62.13 (11.56)
C 152	59.65	60.04 (0.65)	60.98 (2.23)	62.24 (4.34)	62.42 (4.64)
GC 3	55.43	55.68 (0.45)	59.29 (6.96)	60.73 (9.56)	60.65 (9.42)
Mean	56.19	56.71 (0.93)	59.73 (6.30)	60.72 (8.06)	61.28 (9.06)
SE ₊	0.24	0.84	0.31	0.12	0.40
CD at 5%	0.74	2.59	NS	0.35	1.23

Figures in parentheses indicate percent increase over initial stage of seed growth.

4.5.2.3. Starch content

The starch content in seeds influenced by cowpea genotypes at various stages of growth are presented in Table 63. The differences among the genotypes for starch content in seeds were statistically significant at various stages of growth except at 21 DAF.

Table 63. Periodical starch content as influenced by cowpea genotypes

Genotype \ DAF	Starch content (%)				
	9	12	15	18	21
VCM 8	46.62	51.44 (10.34)	51.43 (10.32)	51.19 (9.80)	51.37 (10.19)
Konkan Safed	49.05	52.77 (7.58)	52.75 (7.54)	51.89 (5.79)	50.64 (3.24)
Phule Pandhari	51.67	51.29 (-0.74)	50.51 (-2.25)	50.78 (-1.72)	50.06 (-3.12)
C 152	45.58	48.93 (7.35)	50.58 (10.97)	49.65 (8.93)	49.87 (9.41)
GC 3	49.19	49.27 (0.16)	50.62 (2.91)	50.78 (3.23)	51.84 (5.39)
Mean	48.42	50.74 4.79	51.18 5.70	50.85 5.02	50.76 4.83
SE ₊	0.410	0.225	0.228	0.116	0.218
CD at 5%	1.261	0.693	0.702	0.357	NS

Figures in parentheses indicate percent increase over initial stage of seed growth.

In the present investigation, starch content in seed at 9 DAF was relatively low, however it was constant at advanced stages of seed growth. At 9 DAF, starch content amongst genotypes ranged between 45.58 (C 152) and 51.67% (Phule Pandhari). Konkan Safed had maintained higher starch content at 12 (52.77%), 15 (52.75%) and 18 DAF (51.89%). At 21 DAF, GC 3 recorded higher starch content (51.84%) followed by VCM 8 (51.37%) and Konkan Safed (50.64%).

4.5.3. Fat content

The fat content in seeds influenced by cowpea genotypes at various stages of growth are presented in Table 64. The differences among the genotypes for fat content in seeds were statistically significant at various stages of growth.

Table 64. Periodical fat content as influenced by cowpea genotypes

Genotype \ DAF	Fat content (%)				
	9	12	15	18	21
VCM 8	0.44	1.07 (143.18)	1.15 (161.36)	1.08 (145.45)	1.14 (159.09)
Konkan Safed	0.62	0.94 (51.61)	1.31 (111.29)	1.40 (125.81)	1.61 (159.68)
Phule Pandhari	1.04	1.15 (10.58)	1.55 (49.04)	1.72 (65.38)	1.74 (67.31)
C 152	1.08	1.45 (34.26)	1.60 (48.15)	1.77 (63.89)	1.56 (44.44)
GC 3	0.95	1.13 (18.95)	1.23 (29.47)	1.28 (34.74)	1.15 (21.05)
Mean	0.94	1.15 (22.34)	1.37 (45.74)	1.45 (54.26)	1.44 (53.19)
SE+	0.004	0.089	0.025	0.034	0.083
CD at 5%	0.012	0.274	0.077	0.105	0.256

Figures in parentheses indicate percent increase over initial stage of seed growth.

In the present investigation, fat content in seeds increased progressively upto 18 DAF i.e. seed maturation. At 9 DAF, fat content amongst genotypes ranged between 0.44 (VCM 8) and 1.08% (C 152). C 152 had maintained higher fat at 12 (1.45%), 15 (1.60%) and 18 DAF (1.77%). At 21 DAF, Phule Pandhari recorded

higher fat (1.74%) followed by Konkan Safed (1.61%) and C 152 (1.56%).

4.5.4. Fiber content

The fiber content in seeds influenced by cowpea genotypes at various stages of growth are presented in Table 65. The differences among the genotypes for fiber content in seeds were statistically significant at 9, 12 and 15 DAF.

In the present investigation, the fiber content was higher at initial stages which declined at developing stages and increased with at seed maturation. At 9 DAF, fiber content amongst genotypes ranged between 4.89 (Phule Pandhari) and 6.16% (C 152). Phule Pandhari at 12 (6.23%) and 18 DAF (5.09%), while, C 152 at 15 (5.07%) and 21 DAF (5.31%) maintained higher fiber content.

Table 65. Periodical Fiber content as influenced by cowpea genotypes

Genotype \ DAF	Fiber content (%)				
	9	12	15	18	21
VCM 8	5.29	4.22 (-20.23)	4.47 (-15.50)	4.60 (-13.04)	4.61 (-12.85)
Konkan Safed	5.57	4.61 (-17.24)	4.87 (-12.57)	4.76 (-14.54)	4.87 (-12.57)
Phule Pandhari	4.89	6.23 (27.40)	4.52 (-7.57)	5.09 (4.09)	4.73 (-3.27)
C 152	6.16	4.35 (-29.38)	5.07 (-17.69)	5.03 (-18.34)	5.31 (-13.80)
GC 3	3.45	3.87 (12.17)	4.30 (24.64)	5.01 (45.22)	5.30 (53.62)
Mean	5.07	4.65 (-8.28)	4.65 (-8.28)	4.90 (-3.35)	4.96 (-2.17)
SE ₊	0.004	0.247	0.272	0.147	0.446
CD at 5%	0.012	0.761	0.838	NS	NS

Figures in parentheses indicate percent increase over initial stage of seed growth.

4.5.5. Vitamin content

4.5.5.1. Niacin

The niacin content in seeds influenced by cowpea genotypes at various stages of growth are presented in Table 66. The

differences among the genotypes for niacin content in seeds were statistically significant at various stages of growth.

The genotype C 152 maintained significantly higher niacin content at 9 (2.55 mg/100 g), 15 (2.50 mg/100 g), 18 (2.67 mg/100 g) and 21 DAF (2.61 mg/100 g). Phule Pandhari (2.77 mg/100 g) had higher niacin content at 12 DAF. The genotype, VCM 8 had minimum niacin content amongst all genotypes.

Table 66. Periodical niacin content as influenced by cowpea genotypes

Genotype \ DAF	Niacin content (mg/100 g)				
	9	12	15	18	21
VCM 8	2.15	2.11 (-1.86)	2.17 (0.93)	2.09 (-2.79)	2.22 (3.26)
Konkan Safed	2.25	2.13 (-5.33)	2.25 (0.00)	2.26 (0.44)	2.30 (2.22)
Phule Pandhari	2.47	2.77 (12.15)	2.32 (-6.07)	2.48 (0.40)	2.45 (-0.81)
C 152	2.55	2.34 (-8.24)	2.50 (-1.96)	2.67 (4.71)	2.6 (12.35)
GC 3	2.01	2.05 (1.99)	2.15 (6.97)	2.30 (14.43)	2.36 (17.41)
Mean	2.29	2.28 (-0.44)	2.28 (-0.44)	2.36 (3.06)	2.39 (4.37)
SE ₊	0.005	0.015	0.008	0.021	0.018
CD at 5%	0.015	0.045	0.024	0.064	0.054

Figures in parentheses indicate percent increase over initial stage of seed growth.

4.5.5.2. Thymine

The thymine content in seeds influenced by cowpea genotypes at various stages of growth are presented in Table 67. The differences among the genotypes for thymine content in seeds were statistically significant at 9, 12 and 15 DAF.

The highest and lowest thymine content recorded by the genotypes VCM 8 (0.66 mg/100 g) and C 152 (0.30 mg/100 g) at 9 DAF, respectively. At 12 DAF, Phule Pandhari (0.92 mg/100 g) and VCM 8 (0.86 mg/100 g) had higher thymine content. Konkan Safed

at 15 DAF (0.92 mg/100 g) and GC 3 at 18 (0.95 mg/100 g) and 21 DAF (1.00 mg/100 g) had higher thymine content.

Table 67. Periodical thymine content as influenced by cowpea genotypes

Genotype \ DAF	Thymine content (mg/100 g)				
	9	12	15	18	21
VCM 8	0.66	0.86 (30.30)	0.91 (37.88)	0.90 (36.36)	0.94 (42.42)
Konkan Safed	0.55	0.84 (52.73)	0.92 (67.27)	0.92 (67.27)	0.92 (67.27)
Phule Pandhari	0.54	0.92 (70.37)	0.87 (61.11)	0.91 (68.52)	0.89 (64.81)
C 152	0.30	0.73 (143.33)	0.90 (200.00)	0.92 (206.67)	0.94 (213.33)
GC 3	0.51	0.73 (43.14)	0.83 (62.75)	0.95 (86.27)	1.00 (96.08)
Mean	0.51	0.82 (60.78)	0.89 (74.51)	0.92 (80.39)	0.94 (84.31)
SE ₊	0.002	0.004	0.004	0.022	0.008
CD at 5%	0.007	0.012	0.012	NS	NS

Figures in parentheses indicate percent increase over initial stage of seed growth.

4.5.5.3. B-carotene

The B-carotene in seeds influenced by cowpea genotypes at various stages of growth are presented in Table 68.

Table 68. Periodical B-carotene as influenced by cowpea genotypes

Genotype \ DAF	B-carotene content (mg/100 g)				
	9	12	15	18	21
VCM 8	14.27	23.78 (66.64)	26.23 (83.81)	25.78 (80.66)	27.33 (91.52)
Konkan Safed	13.12	23.48 (78.96)	27.84 (112.20)	28.80 (119.51)	30.22 (130.34)
Phule Pandhari	19.34	24.34 (25.85)	27.77 (43.59)	29.81 (54.14)	29.40 (52.02)
C 152	11.68	23.29 (99.40)	28.59 (144.78)	30.67 (162.59)	29.65 (153.85)
GC 3	17.17	17.98 (4.72)	25.12 (46.30)	28.54 (66.22)	28.70 (67.15)
Mean	15.11	22.57 (49.37)	27.11 (79.42)	28.72 (90.07)	29.06 (92.32)
SE ₊	0.998	1.300	0.340	0.454	0.622
CD at 5%	3.075	4.005	1.048	1.399	NS

Figures in parentheses indicate percent increase over initial stage of seed growth.

The differences among the genotypes for *B*-carotene in seeds were statistically significant at various stages of growth except at 21 DAF. The highest and lowest *B*-carotene recorded by the genotypes Phule Padhari (19.34 mg/100 g) and C 152 (11.68 mg/100 g) at 9 DAF, respectively. At 12 DAF, Phule Pandhari (24.34 mg/100 g) and VCM 8 (23.78 mg/100 g) had higher *B*-carotene. The genotypes, C 152 at 15 (28.59 mg/100 g) and 18 DAF (30.67 mg/100 g) and Konkan Safed (30.22 mg/100 g) at 21 DAF had higher *B*-carotene.

4.5.6. Chlorophyll content in pod wall

4.5.6.1. Chlorophyll 'a'

The chlorophyll 'a' content in pod wall influenced by cowpea genotypes at various stages of growth are presented in Table 69. The differences among the genotypes for chlorophyll 'a' content in pod wall were statistically significant at different stages of growth.

The genotype GC 3 (0.4653 mg/g) recorded highest chlorophyll 'a' at 3 DAF followed by Phule Pandhari (0.4063 mg/g) and VCM 8 (0.3920 mg/g) in pod wall. However, at 6 DAF, Phule Pandhari (0.4389 mg/g) and VCM 8 (0.4242 mg/g) maintained highest chlorophyll 'a' content in pod walls. At 9 DAF also, Phule Pandhari (0.3864 mg/g) and VCM 8 (0.3689 mg/g) found to be promising for chlorophyll 'a' content in pod wall. C 152 (0.3380 mg/g) and GC 3 (0.3066 mg/g) had highest chlorophyll 'a' at 12 DAF in pod wall. At 15 DAF, GC 3 (0.2496 mg/g) and Phule Pandhari (2447 mg/g) had highest chlorophyll 'a' content in pod walls. The genotypes, C 152 (0.1205 mg/g) and VCM 8 (0.0984 mg/g) were significantly superior for chlorophyll 'a' content in pod wall at 18 DAF over rest of the genotypes.

Table 69. Periodical Chlorophyll 'a' content in pod walls as influenced by cowpea genotypes

Genotype \ DAF	Chlorophyll 'a' content (mg/g)					
	3	6	9	12	15	18
VCM 8	0.3920	0.4242	0.3689	0.2712	0.2247	0.0984
Konkan Safed	0.3291	0.1977	0.1980	0.1828	0.1299	0.0520
Phule Pandhari	0.4063	0.4389	0.3864	0.2898	0.2447	0.0684
C 152	0.3266	0.3563	0.2860	0.3380	0.2395	0.1205
GC 3	0.4653	0.3469	0.3096	0.3066	0.2496	0.0517
Mean	0.3838	0.3528	0.3098	0.2777	0.2177	0.0782
SE _±	0.0155	0.0117	0.0114	0.0128	0.0052	0.0040
CD at 5%	0.0478	0.0362	0.0351	0.0396	0.0161	0.0123

Table 70. Values of regression co efficient of polynomials fitted for Chlorophyll 'a' content in cowpea pod wall from the stage of flowering

Genotype	Values of regression co efficient				R ²
	b ₀	b ₁	b ₂	b ₃	
VCM 8	0.3122	0.0422	-0.0049	0.0001	0.9814
Konkan Safed	0.5494	-0.1007	0.0093	-0.0003	0.9773
Phule Pandhari	0.3603	0.0252	-0.0026	--	0.9764
C 152	0.3662	-0.0182	0.0028	-0.0001	0.9089
GC 3	0.7660	-0.1372	0.0139	-0.0005	0.9993

An attempt to fit polynomial of changes in chlorophyll 'a' content during ontogeny against time from flowering indicated that, the values of R² approaches the benchmark value above 0.90 for this character (Table 70). VCM 8, Konkan Safed, C 152 and GC 3 showed cubic polynomial equation, while Phule Pandhari had a quadrilateral equation as a good fit. Genotypes, Konkan Safed, C 152 and GC 3 showed polynomial regression equation, Y (chl. 'a' content) = $b_0 - b_1 + b_2 - b_3$, $Y = b_0 + b_1 - b_2 + b_3$ for VCM 8 and $Y = b_0 + b_1 - b_2$ for Phule Pandhari as a good fit. The positive b_0 values indicated that the initial rate of chlorophyll 'a' content was higher

than that of the later stages. The higher values for b_0 and lower values for b_1 in GC 3 revealed that the initial chlorophyll 'a' content was higher. In contrast, VCM 8 exhibited minimum b_0 and maximum b_1 means the lower rate of initial chlorophyll 'a' content.

4.5.6.2. Chlorophyll 'b'

The chlorophyll 'b' content in pod wall influenced by cowpea genotypes at various stages of growth are presented in Table 71. The differences among the genotypes for chlorophyll 'b' content in pod wall were statistically significant at different stages of growth except at 9 DAF.

Table 71. Periodical chlorophyll 'b' content in pod wall as influenced by cowpea genotypes

Genotype \ DAF	Chlorophyll 'b' content (mg/g)					
	3	6	9	12	15	18
VCM 8	0.3715	0.3372	0.2886	0.2052	0.1873	0.0908
Konkan Safed	0.3224	0.2098	0.2464	0.1507	0.1148	0.0488
Phule Pandhari	0.3476	0.3367	0.2996	0.2356	0.1903	0.0564
C 152	0.3951	0.3671	0.2802	0.3060	0.2108	0.1095
GC 3	0.4168	0.2797	0.2606	0.2315	0.1841	0.0232
Mean	0.3707	0.3061	0.2751	0.2258	0.1775	0.0657
SE _±	0.0173	0.0114	0.0126	0.0096	0.0077	0.0035
CD at 5%	0.0533	0.0350	NS	0.0295	0.0239	0.0107

The genotype GC 3 (0.4168 mg/g) recorded highest chlorophyll 'b' at 3 DAF followed by C 152 (0.3951 mg/g) and VCM 8 (0.3715 mg/g) in pod wall. At 6 DAF, C 152 (0.3671 mg/g) maintained higher chlorophyll 'b' content followed by VCM 8 (0.3372 mg/g) and Phule Pandhari (0.3367 mg/g) in pod wall. At 9 DAF, Phule Pandhari (0.2996 mg/g) ranked highest followed by VCM 8 (0.2886 mg/g) and C 152 (0.2802 mg/g) for chlorophyll 'b' content in pod walls. C 152 (0.3060 mg/g), Phule Pandhari (0.2356 mg/g) and GC 3 (0.2315 mg/g) had highest chlorophyll 'b' at 12

DAF in pod wall. At 15 DAF, C 152 (0.2108 mg/g), Phule Pandhari (0.1903 mg/g) and VCM 8 (0.1876 mg/g) had highest chlorophyll 'b' content in pod wall. The genotypes, C 152 (0.1095 mg/g) and VCM 8 (0.0908 mg/g) were significantly superior for chlorophyll 'b' content in pod wall at 18 DAF over other genotypes.

An attempt to fit polynomial of changes in chlorophyll 'b' content during ontogeny against time from flowering indicated that the values of R^2 approaches the benchmark value above 0.90 for this character (Table 72). Konkan Safed, C 152 and GC 3 showed cubic polynomial equation, whereas, Phule Pandhari and VCM 8 showed quadrilateral equation as a good fit. Genotypes, Konkan Safed, C 152 and GC 3 showed polynomial regression equation, Y (chl. 'b' content) = $b_0 - b_1 + b_2 - b_3$, $Y = b_0 - b_1 - b_2$ for VCM 8 and $Y = b_0 - b_1 + b_2$ for Phule Pandhari as a good fit. The positive b_0 values indicated that the initial rate of chlorophyll 'b' content was higher than that of the later stages. The higher values for b_0 and lower values for b_1 in GC 3 revealed that the initial chlorophyll 'b' content was higher. In contrast, Phule Pandhari exhibited minimum b_0 and maximum b_1 means the lower rate of initial chlorophyll 'b' content.

Table 72. Values of regression coefficient of polynomials fitted for Chlorophyll 'b' content in cowpea pod wall from the stage of flowering

Genotype	Values of regression coefficient				R^2
	b_0	b_1	b_2	b_3	
VCM 8	0.4139	-0.0126	-0.0001	--	0.9804
Konkan Safed	0.4222	-0.0456	0.0033	-0.0001	0.9253
Phule Pandhar	0.3732	-0.0088	0.0006	--	0.9907
C 152	0.5006	-0.0439	0.0039	-0.0002	0.9572
GC 3	0.6982	-0.1278	0.0123	-0.0004	0.9975

4.5.3.3. Total chlorophyll

The total chlorophyll content in pod wall influenced by cowpea genotypes at various stages of growth are presented in Table 73. The differences among the genotypes for total chlorophyll content in pod wall were statistically significant at different stages of growth.

The genotype GC 3 (0.9522 mg/g) recorded highest chlorophyll content at 3 DAF followed by VCM 8 (0.8500 mg/g) and Phule Pandhari (0.8449 mg/g) in pod wall. At 6 DAF, Phule Pandhari (0.9044 mg/g) maintained higher chlorophyll content followed by VCM 8 (0.8884 mg/g) and C 152 (0.8174 mg/g) in pod wall. At 9 DAF, Phule Pandhari (0.7790 mg/g) ranked highest followed by VCM 8 (0.7449 mg/g) and GC 3 (0.6580 mg/g) for total chlorophyll content in pod walls. C 152 (0.7384 mg/g), GC 3 (0.6247 mg/g) and Phule Pandhari (0.6065 mg/g) had highest total chlorophyll content at 12 DAF in pod wall. At 15 DAF, C 152 (0.5094 mg/g), GC 3 (0.5072 mg/g) and Phule Pandhari (0.5029 mg/g) had highest chlorophyll content in pod walls. The genotypes, C 152 (0.2623 mg/g) and VCM 8 (0.2102 mg/g) were significantly superior for chlorophyll content in pod wall at 18 DAF over other genotypes.

An attempt to fit polynomial of changes in chlorophyll content during ontogeny against time from flowering indicated that the values of R^2 approach the benchmark value above 0.90 for this character (Table 74). Except Phule Pandhari all genotypes showed cubic polynomial equation as a good fit. Genotypes, Konkan Safed, C 152 and GC 3 showed polynomial regression equation, Y (total chlorophyll) = $b_0 - b_1 + b_2 - b_3$, $Y = b_0 + b_1 - b_2 + b_3$ for VCM 8 and $Y = b_0 + b_1 - b_2$ for Phule Pandhari as a good fit. The positive b_0 values indicated that the initial rate of total chlorophyll content was higher

than that of the later stages. The higher values for b_0 and lower values for b_1 in GC 3 and Konkan safed revealed that the initial chlorophyll content was higher. In contrast, VCM 8 and Phule Pandhari exhibited minimum b_0 and maximum b_1 means the lower rate of initial chlorophyll content.

Table 73. Periodical chlorophyll content in pod walls influenced by cowpea genotypes

Genotype \ DAF	Total chlorophyll content (mg/g)					
	3	6	9	12	15	18
VCM 8	0.8500	0.8884	0.7449	0.5493	0.4797	0.2102
Konkan Safed	0.7261	0.4522	0.4638	0.3746	0.2776	0.1080
Phule Pandhari	0.8449	0.9044	0.7790	0.6065	0.5029	0.1529
C 152	0.8029	0.8174	0.6363	0.7384	0.5094	0.2623
GC 3	0.9522	0.7261	0.6580	0.6247	0.5072	0.0899
Mean	0.8452	0.7577	0.6564	0.5787	0.4554	0.1646
SE _±	0.0335	0.0319	0.0249	0.0224	0.0101	0.0069
CD at 5%	0.1031	0.0984	0.0769	0.0692	0.0313	0.0213

Table 74. Values of regression coefficient of polynomials fitted for total Chlorophyll content in cowpea pod wall from the stage of flowering

Genotype	Values of regression coefficient				R ²
	b_0	b_1	b_2	b_3	
VCM 8	0.7715	0.0513	-0.0073	0.0002	0.9741
Konkan Safed	1.1379	-0.1868	0.0165	-0.0005	0.9752
Phule Pandhar	0.7793	0.0396	-0.0043	--	0.9794
C 152	0.9533	-0.0646	0.0073	-0.0003	0.9242
GC 3	1.5183	-0.2584	0.0263	-0.0009	0.9992

4.6. Morphological characterization

The morphological characterization of five cowpea genotypes was done as per the National Test Guidelines developed for DUS testing.

The results of morphological characterization of cowpea genotypes under study are presented in Table 75 and 76.

It is seen that, some of the states of morphological characteristics were not observed in the genotypes *viz.* poor plant vigour, purple seedling pigmentation, purple pigmentation on leaflets, poor branching, and rough seed surface texture.

Among the five genotypes studied, the genotypes Konkan Safed and C 152 were very distinct as it had light pigmentation on seedlings. Remaining genotypes had dark green pigmentation on seedlings (Character No. 1). The pigmentation on leaflets was as like appeared on seedlings (Character No. 2) in all the genotypes. The early genotype VCM 8 and GC 3 were distinct since the early plant vigour of the genotypes was categorized as very good, whereas, the remaining genotypes had good early plant vigour (Character No. 3).

The genotype VCM 8 was distinct in respect of plant height. It had determinant type of growth habit, whereas the remaining genotypes were of indeterminant type of growth habit (Characteristic No. 4). Konkan Safed, VCM 8 and GC 3 possessed profuse branching, whereas, Phule Pandhari and C 152 had medium branching (characteristic No. 5).

The genotype GC 3 could be identified from the five genotypes studied on the basis of stem colour, since it had purple stem colour. Konkan Safed and C 152 had light green stem colour. Whereas, VCM 8 and Phule Pandhari had dark green stem colour (characteristic No. 6).

The genotype Konkan Safed had light green foliage colour, whereas, C 152 and Phule Pandhari had green foliage. The genotypes GC 3 and CVM 8 were identified on the basis of dark green foliage colour (characteristic No. 7).

From the leaflet margin of the genotypes viz. VCM 8 and GC 3 were categorized as medium leaflet margin, whereas, Konkan Safed, C 152 and Phule Pandhari had high leaflet margin (characteristic No. 8).

The genotype Konkan Safed had very specific creamy white flower colour, whereas the genotypes VCM 8 and GC 3 had light bluish colour. The remaining genotypes viz. Phule Pandhari and C 152 had dark blue flower colour (characteristic No. 9).

The genotype VCM 8 had small pod size at maturity, whereas, the genotype Phule Pandhari had medium at maturity. Remaining genotypes viz. GC 3, C 152 and Konkan Safed had high pod size at maturity (characteristic No. 10).

The genotypes Konkan Safed had bold seed size, whereas, Phule Pandhari and C 152 small seed size (100 seed weight). The genotypes, VCM 8 and GC had medium seed size (characteristic No. 11).

The genotype Konkan Safed was very distinct from the other genotypes in respect to seed shape. It had oblong seed shape, whereas other genotypes were elongated type of seeds (characteristic No. 12). All the genotypes under study had smooth seed surface texture (characteristic No. 13).

The genotype Konkan Safed had very specific milky white seed colour. The genotypes, GC 3 and VCM 8 were especially cream white colour. Remaining genotypes viz. C 152 and Phule Pandhari had red seed colour.

Table 75. Morphological characterization of cowpea genotypes**1. Seedling pigmentation**

Dark green	Light green	Purple
VCM 8, GC 3, Phule Pandhari	Konkan Safed, C 152	---

2. Plant coloration on leaflet

Dark green	Light green	Purple
VCM 8, GC 3, Phule Pandhari	Konkan Safed, C 152	---

3. Early plant vigor

Very good	Good	Poor
VCM 8, GC 3	Phule Pandhari , Konkan Safed, C 152	--

4. Plant growth habit

Determinate	Indeterminate
VCM 8	GC 3, Phule Pandhari, Konkan Safed, C 152

5. Branching

Less	Medium	Profuse
-----	Phule Pandhari , C 152	Konkan Safed, VCM 8, GC 3

6. Stem colour

Dark green	Light green	Purple
VCM 8, Phule Pandhari	Konkan Safed, C 152	GC 3

7. Foliage colour

Light green	Green	Dark green
Konkan Safed	C 152, Phule Pandhari	VCM 8, GC 3

8. Leaflet margin

Medium	High
VCM 8, GC 3	Konkan Safed, C 152, Phule Pandhari

9. Flower colour

White	Light blue	Dark blue
Konkan Safed	VCM 8, GC 3	Phule Pandhari, C 152

10. Pod size at maturity

Small	Medium	High
VCM 8	Phule Pandhari	GC 3, C 152, Konkan Safed

11. Seed size (100-seed weight)

Small	Medium	High
Phule Pandhari, C 152	GC 3, VCM 8	Konkan Safed

12. Seed shape

Elongated	Oblong
VCM 8, GC 3, C 152, Phule Pandhari	Konkan Safed

13. Seed surface texture

Smooth	Rough
VCM 8, GC 3, C 152, Phule Pandhari, Konkan Safed	---

14. Seed colour

Milky white	Creamy white	Red
Konkan Safed	GC 3, VCM 8	C 152, Phule Pandhari

Table 76. Morphological characterization in five cowpea genotypes

Characters	VCM 8	Konkan Safed	Phule Pandhari	C 152	GC 3
Seedling pigmentation	Dark green	Light green	Dark green	Dark green	Light green
Plant coloration on leaflet	Dark green	Light green	Dark green	Dark green	Light green
Early plant vigor	Very good	Good	Good	Good	Very good
Plant growth habit	Determinate	Indeterminate	Indeterminate	Indeterminate	Indeterminate
Branching habit	Profuse	Profuse	Medium	Medium	Profuse
Stem colour	Dark green	Light green	Dark green	Light green	Purple
Foliage colour	Dark green	Light green	Green	Green	Dark green
Leaflet margin	Medium	High	High	High	Medium
Flower colour	Yellow purple	White	Purple	Purple	Yellow purple
Pod size at maturity	Small	High	Medium	High	High
Seed size (100-seed wt.)	Medium	High	Small	Small	Medium
Seed shape	Elongated	Oblong	Elongated	Elongated	Elongated
Seed surface texture	Smooth	Smooth	Smooth	Smooth	Smooth
Seed colour	Creamy white	Milky white	Red	Red	Creamy white

5. DISCUSSION

In crop science, for understanding of the causes for variation in grain yield as well as for attempts towards increasing grain yield, physiological approach is the basic. Plant growth analysis is an explanatory, holistic and integrative approach to interpreting plant form and function. It uses simple primary data in the form of weights, areas, volumes and contents of plant components to investigate processes within and involving the whole plant (Evans, 1972; Causton and Venus, 1981; Hunt, 1990).

The pod of the legume provides a protective envelope to the developing seeds; it acts as catchments, transport link, and temporary reservoir for solutes mobilized from vegetative parts to seeds; and if green and illuminated, it functions significantly in photosynthetic fixation of CO₂ (Crookston *et al.*, 1974).

The results obtained in the present investigation on pod ontogeny cover the events from appearance of floral bud, anthesis, setting of pods, development of pod shell, elongation and dry matter accumulation in pod shell, setting of seeds into pod and growth of grain in terms of length, breadth and width are discussed in this chapter.

5.1. Characters of pod development

In the ontogeny of pod formation, the initial phase is always characterized by emergence of flower, pod formation and seed development, their growth and a developmental step that enters into mature pod and seed. The results in relation to various events from setting of floral bud till maturity of pods in context of various growth characters, pod and seed filling rates in relation to length of pod and size of seeds and total, actual and effective filling periods and their relation with actual and effective filling rates in cowpea varieties were investigated.

The integrated history of events in pod development can be precisely studied from empirical models constructed for such components of pod development. Use of polynomials constructed from the data on series of observations is an established practice in physiological studies. Such polynomial curves fitted with adequate accuracy and summarized the growth data in a convenient way. Moreover, the original data distributed by irregular errors are replaced by smoother continuous functions.

5.1.1. Fresh and dry weight of flower

Reproductive growth in cowpea is initiated by flowering and a period of pod or seed set (Egli, 2005). The number of pods or seeds that the crop community produces is determined during this period and this number determines, in large part, the final grain yield (Egli, 1998). The distribution of flower and pod production during flowering may be an important determinant of pod and seed number in grain crops (Egli and Bruening, 2005).

In the present investigations, the ratio between fresh and dry weight of flower was 1:10. The genotypes, GC 3 and Konkan Safed recorded highest fresh and dry weight. VCM 8 recorded least fresh and dry weight. Amongst these, Konkan Safed had long pods and bold seeds whereas VCM being short pods and small grains. Therefore, it may be concluded that the dry matter accumulation in flower and/ or flower size may be correlated with pod and seed size in cowpea.

5.1.2. Pod growth

The periodical changes in pod length, girth and diameter are depicted in Fig 1. It revealed that, the pod length was increased progressively with the advancing age of crop upto 12 to 15 DAF, thereafter, it declined towards maturity due to drying of pods. The loss of moisture in maturing seed is an inherent phase of seed

development (Kolhe and Chavan, 1964; Manohar and Sachan, 1974). Mayer (1973) stated that accumulation of dry matter with loss of moisture as the characteristic feature during seed development and maturation. Aryeetey and Laing (1973) reported high heritability estimates for pod length. Natarajan and Srimathi (2008) observed decrease in moisture content of pod with advancement in maturation correlated with higher dehydration rate of pod at maturity (Manohar and Sachan, 1974; Sabir-Ahamed, 1989).

The rate of increase in pod length was rapid in early maturing genotypes VCM 8 and GC 3 i.e. upto 12 DAF. However, in late maturing genotypes, *viz.* Konkan Safed, Phule Pandhari and C 152 it was at slower rate i.e. upto 15 DAF. Ogunbodede and Fatula (1985) reported a higher estimate of narrow sense heritability for pod length and seed size.

The pod girth was increased progressively upto 12 DAF in VCM 8 and upto 15 DAS in other genotypes, thereafter it declined towards maturity due to loss of moisture from pods. The genotype Phule Pandhari has rapid increase in pod girth during the course of growth from the extremely small value at 0 times i.e. at anthesis.

The pod diameter was increased progressively upto 12 DAF in VCM 8, whereas it was increased progressively upto 15 DAF in other genotypes, thereafter, it declined towards maturity due to loss of moisture from pods. Polynomial as a good fit for pod diameter suggested that in Phule Pandhari and C 152 rapid rate for growth of pod diameter, whereas, VCM 8 and GC slower rate for pod growth was observed.

5.1.3. Seed growth

The periodical changes in polar and equatorial diameter of seed are depicted in Fig 1. The polar diameter was increased

progressively upto 12 DAF in VCM 8, whereas, it was increased progressively upto 15 DAF in other genotypes, thereafter it declined towards maturity due to loss of moisture from seeds.

The equatorial diameter of seed was increased progressively upto 15 DAF in all genotypes, thereafter, it declined towards maturity due to loss of moisture from seeds resulting into reduction of seed size. Quadratic polynomial fittings showed that, VCM 8 and Konkan Safed had faster seed growth rate, whereas, C 152 and Konkan Safed exhibited slower rate of seed growth.

5.1.4. Pod and seed volume

The periodical changes in pod and seed volume are depicted in Fig 2. The rate of increase of pod volume was rapid in VCM 8 which completes its full growth within 12 DAF. However, remaining genotypes required 15 DAF for full growth of green pods. Afterwards the pod volume decreased toward maturity due to loss of moisture resulting in contraction of pods.

The seed volume increased progressively upto 12 DAF in VCM 8, Konkan Safed and C 152. However, in Phule Pandhari and GC 3 the period was extended 3 more days for increasing seed volume. Afterwards there was a reduction in seed volume towards maturity due to reduction in moisture content from seeds.

With the quadratic curve as an appropriate fit, the highest value of b_1 and lowest value of b_0 in VCM 8 revealed faster rate of increase in pod and seed volume. In contrast, Konkan Safed and C 152 exhibited least value for b_1 and high b_0 indicating the slower rate of increase in pod and seed volume.

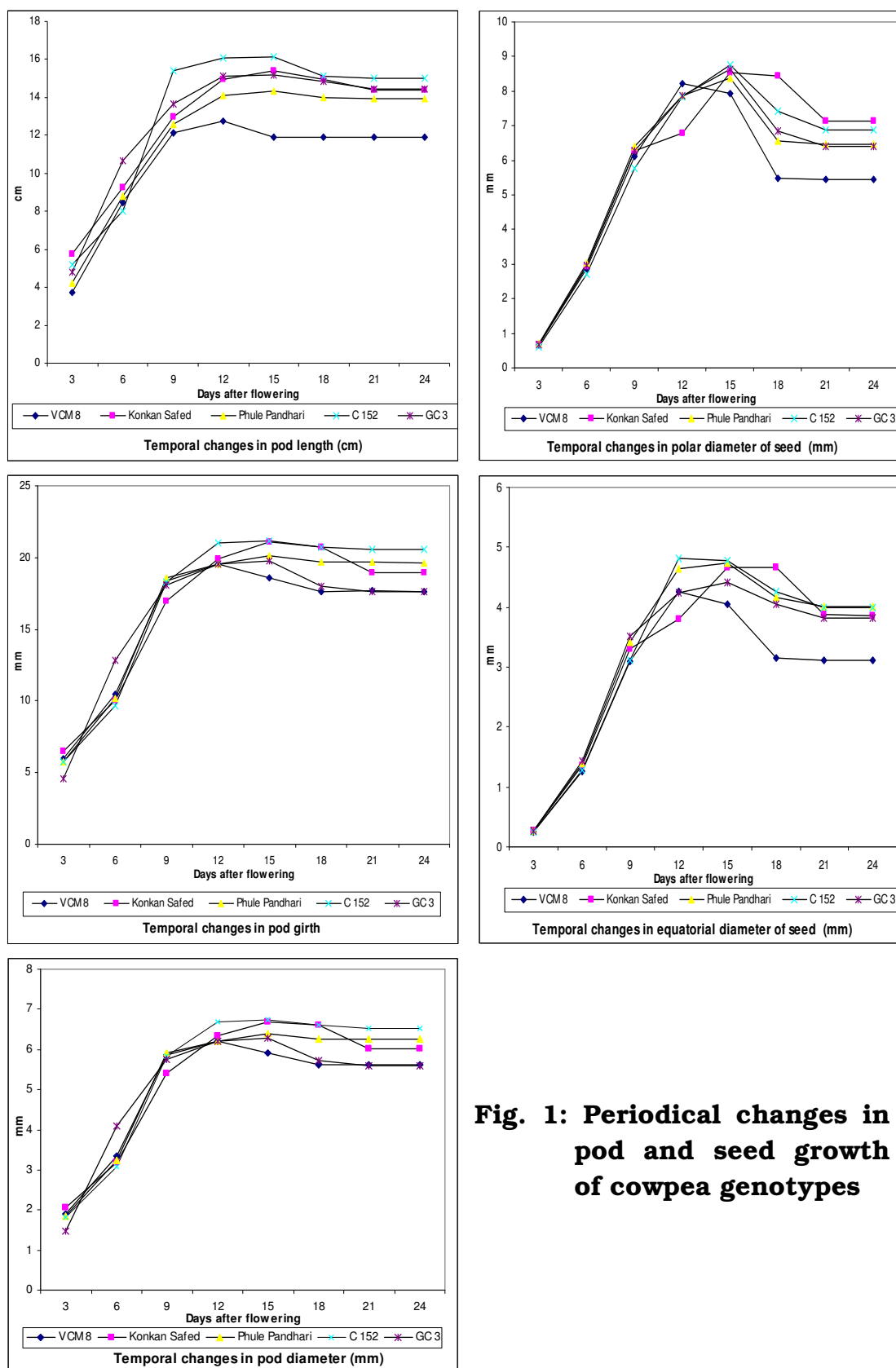


Fig. 1: Periodical changes in pod and seed growth of cowpea genotypes

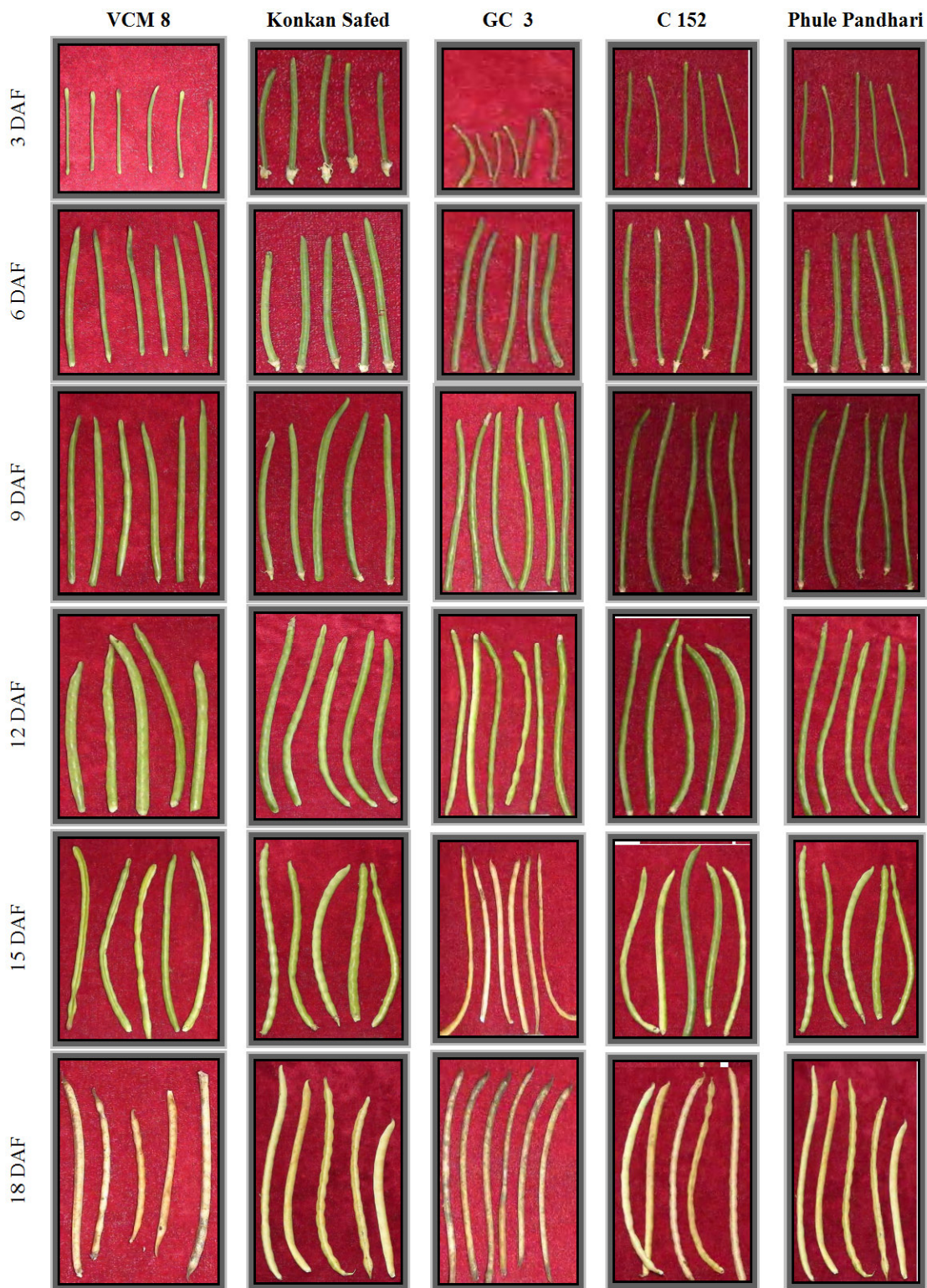


Plate 2. Periodical changes in pod growth.

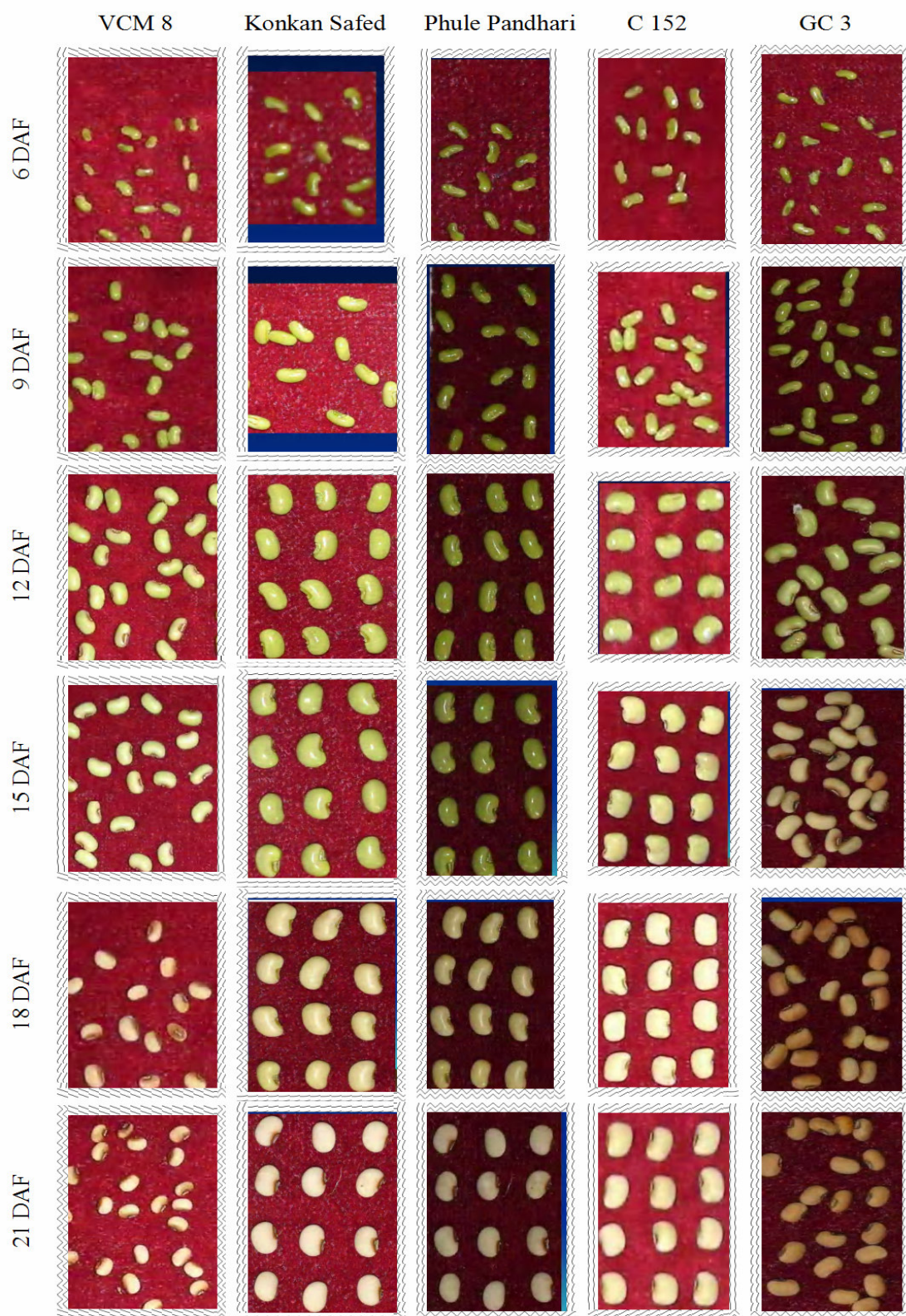


Plate 3. Periodical changes for seed growth.

5.1.5. Fresh weight of pod and it's components parts

The periodical changes in fresh and dry weight of pod wall, pods and seeds/pod of cowpea genotypes are shown in Fig 2. The maximum fresh weight in pod wall was at 9 DAF in VCM 8 and C 152. However, maximum fresh weight of pod wall in Konkan Safed, Phule Pandhari and GC 3 was at 12 DAF. Afterwards it rapidly declined with the advancing age of the crop due to rapid reduction in moisture. Li Wang and Grusak (2005) given a detailed developmental characterization of pod walls at the four time points (3, 6, 13 and 20 DPP).

The maximum fresh weight in pod was at 12 DAF in early maturity group genotypes VCM 8 and GC 3. Whereas, genotypes from late and midlate maturity groups *viz.* Konkan safed, Phule Pandhari and C 152 required 15 DAF for maximum fresh weight in pod. Afterwards it rapidly declined with the advancing age of the crop due to rapid reduction in moisture.

The maximum fresh weight in seeds/ pod was at 12 DAF in VCM 8. Whereas, maximum fresh weight in seeds/ pod in other genotypes was at 15 DAF. Afterwards, it rapidly declined with the advancing age of the crop due to rapid moisture reduction from seeds.

An attempt to fit polynomial of changes in during ontogeny against time for fresh weight of pod wall, pod and seeds/ pod from flowering indicating that, VCM 8 and GC 3 had faster rate of increase in fresh weights of pod wall, whereas, Phule Pandhari, Konkan safed and C 152 had faster rate of increase in fresh weight of pod and seeds/pod.

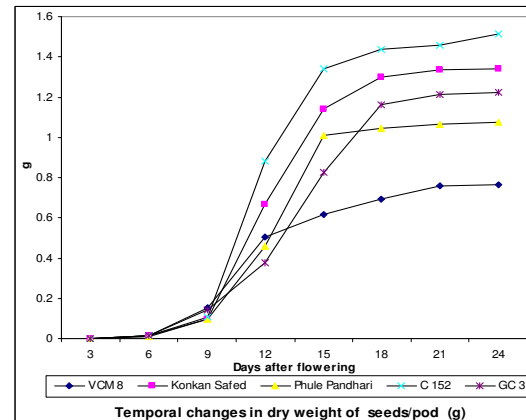
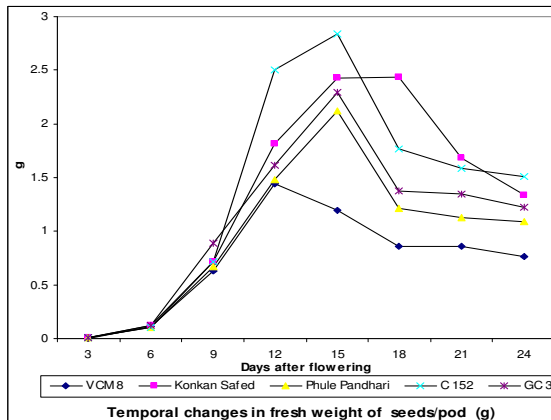
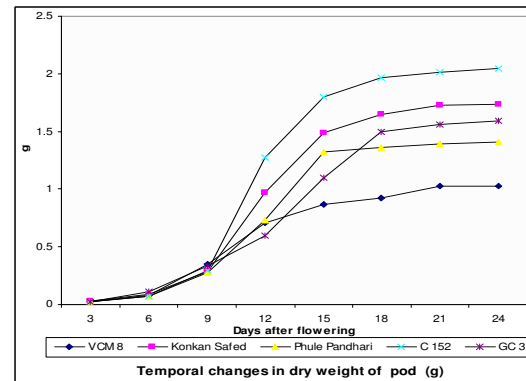
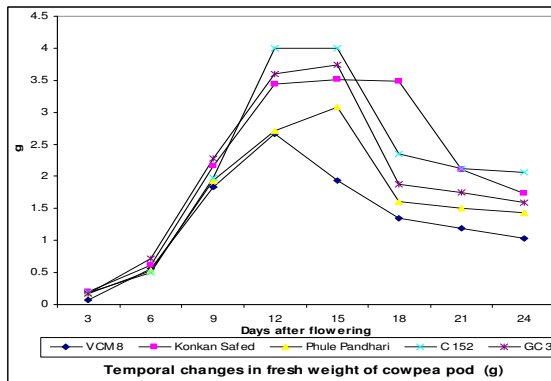
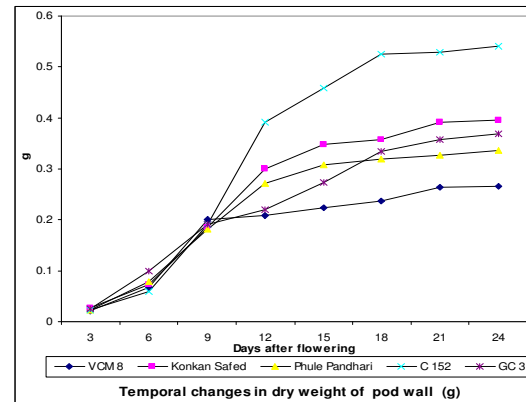
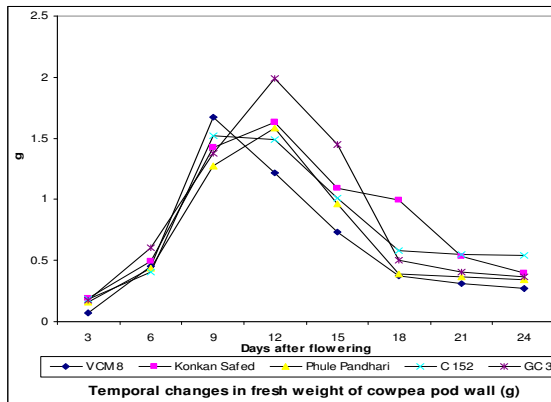
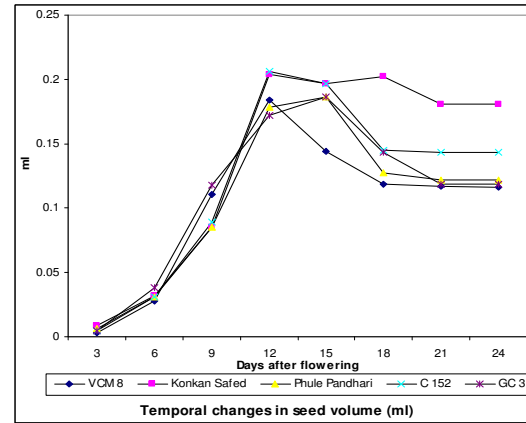
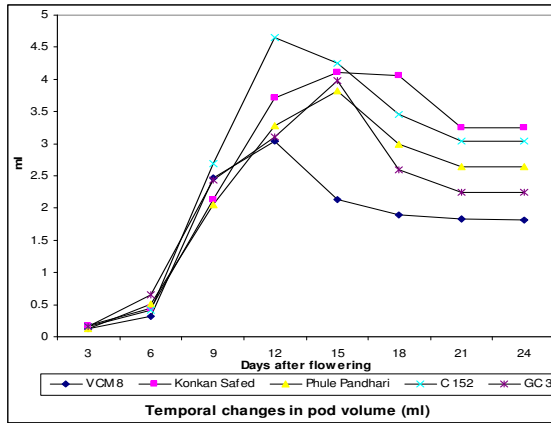


Fig. 2: Periodical changes in pod and seed volume and fresh and dry weights of cowpea pod and its components

5.1.6. Dry weight of pod and its component parts

Reproductive plant organs impose a significant energy and carbon demand in relation to the total plant dry mass production (Bazzaz *et al.*, 1979), since significant quantities of assimilates are translocated from leaves to flowers and developing fruits (Pavel and DeJong, 1993). Several studies have reported that flowers and pods of legumes have photosynthetic activity (Hansen, 1970; Crookston *et al.*, 1974; Flinn *et al.*, 1977), and so these reproductive structures should contribute with a fraction of the carbohydrates required for their development.

The periodical changes for dry weight of pod wall, seeds/ pod and pod of cowpea genotypes are depicted in Fig 2. The dry weight in pod wall increased progressively with advancing age of the crop. The genotype GC 3 had higher rate of dry matter accumulation in pod wall at initial stages. However, at 9 DAF, C 152 had higher rate of dry matter accumulation in pod wall followed by Konkan Safed and GC 3. Milford *et al.*, (1999) demonstrated that maximum DM and N contents of the pod wall were at the end of pod extension. Chaturvedi *et al* (1980) reported that the dry matter accumulation in fruit wall increase progressively.

There was a non-significant difference amongst the genotypes for dry weight of seeds per pod upto 9 DAF. After 12 DAF, genotype C 152 recorded higher rate of dry matter accumulation in seeds per pod at various stages of growth followed by Konkan Safed and GC 3.

The dry weight of pod increased progressively with advancing age of the crop. The genotype GC 3 had higher rate of dry matter accumulation in pod wall at initial stages upto 9 DAF. After 12

DAF, C 152 maintained higher rate of dry matter accumulation in pod wall followed by Konkan Safed and GC 3.

The genotype, Phule Pandhari had highest value of b_1 and lowest value of b_0 revealed that the rate of increase in dry matter of pod wall, seeds/ pod and pods was higher than other genotypes. Lagunes-Espinoza (2003) showed the additive inheritance for proportion of pod wall, seed weight per pod and mean seed weight.

5.1.7. Seed / pod growth rate

Seed/ pod growth rate and relative growth rate of seed and pod of cowpea genotypes at various stages of growth are presented in Fig 3. The seed growth rate increased progressively with the advancing age of the crop. The rate of seed growth was rapid between 6 and 12 DAF in VCM 8. In other genotypes, it increased rapidly between 6 and 15 DAF. Thereafter, the growth rate was increased steadily in VCM 8, Konkan Safed, C 152 and CG 3, whereas, it was at constant rate in Phule Pandhari.

The genotype C 152 maintained higher seed growth rate followed by Konkan Safed and GC 3 at various stages of growth. Munier Jolain *et al.*, (1998) stated that the dry weight of harvested grain legume seeds is strongly related to their growth rate. Guffy *et al.* (1991) studied seed growth rate and duration of growth for soybean [*Glycine max* (L.) Merr.] cultivars.

The pod growth rate increased progressively with the advancing age of the crop in all genotypes. The pod growth rate of VCM 8 was increased steadily from flowering towards maturity. In other genotypes, the initial rate was rather slow which turns to rapid rate between 6 and 15 DAF as grand growth period and becomes steady towards maturity. C 152 maintained highest pod growth rates at various stages of growth followed by Konkan Safed and GC 3. Babu and Kailasum (1988) studied that the pod filling

rate or duration of pod filling greatly decide final pod weight in greengram and blackgram.

5.1.8. Relative growth rate of seeds and pod

Relative growth rate of seeds and pod at various stages of growth are depicted in Fig 16. The relative growth rate of seeds declined towards maturity. The genotypes under study exhibited independent behaviors for relative growth rate of seeds. The relative growth rate of seeds for VCM 8 and C 152 was initially rather high which declined towards maturity. However, the relative growth rate of seeds in Konkan Safed between 9 and 12 DAF, Phule Pandhari between 6 and 9 DAF and GC 3 between 12 and 15 DAF were higher than the initial stage, which declined towards maturity. Johnson and Turner (1972) suggested that grain yield was a function of the rate and duration of dry matter accumulation in the grain. Guffy *et al.* (1991) studied seed growth rate and duration of growth for different soybean cultivars. Munier-Jolain *et al* (1996) analyzed final seed weight as the product of seed growth rate and duration of seed filling.

The relative growth rate of pods increased between stages 3-6 and 6-9 DAF, thereafter, it declined towards maturity. The genotypes under study exhibited independent behaviors for relative growth rate of pods. The relative growth rate of seeds increased upto 6-9 DAF for VCM 8 and Phule Pandhari whereas in Konkan Safed and C 152 it increased upto 9-12 DAF. Thereafter, it declined towards maturity. However, in GC 3 it reduced upto 9-12 DAF and slightly increased at the stage of 12-15 DAF. Thereafter it decreased towards maturity. Kaur *et al.* (2008) reported that the seed growth rate, seed fill duration, seed number, and average seed weight and size decreased greatly in the plants.

5.2. Actual/effective pod/ seed development periods

It is well known that the production of yield in field crops depends upon the accumulation of dry matter in seeds. Wien and Ackah (1978) have proposed that the amount of seed yield produced is the product of the number of seeds and their size, determined by the rate and duration of dry matter accumulation.

The investigation of pod development and seed development, therefore, constitute the basic issue in deciding the final grain yield.

The events of pod development includes the appearance of flower bud, opening of flower, setting of pods, elongation of pods, width and girth wise growth of pods and achievement of the final pod volume and deposition of photosynthates into pod wall. This was required for setting and growth of seeds in pod shell.

On an average 42.10 days were required for first floral bud and within next day flowering occurred. In next two days, the pod setting occurred. The period for floral bud initiation to pod setting was less than other pulses. The maximum length, breadth and diameter of pods and seed were achieved within 12 days after flowering in VCM 8, while it was achieved in other genotypes within 15 days after flowering. The maximum fresh weights in seeds, pods and pod shell were between 12 and 15 days after flowering in all genotypes. The maximum dry weights in pod shell, seeds and pods were achieved within 18 days after flowering in VCM 8, while in other genotypes it was achieved within 21 days after flowering.

Thus, the whole process of development of pod shell and seeds in pod occurred within 12 DAF in VCM 8 and 15 DAF in other genotypes. Thereafter, losses of moisture from pods initiated and the desiccation of seeds occurred towards maturity. On account of this it suggested that the period for full development of pod requires 12-15 days after flowering and next 6 days period

requires for seed drying. Totally, 17-21 days were required as a pod and seed development periods.

A critical perusal indicated that the deposition of assimilates into pod shell was the earliest event before complete elongation, widening and achievement of final pod volume. This suggested that assimilates are gathered at the beginning in the sink and then they are utilized for development of pod in entire dimension.

5.2.1. Actual and effective pod development periods

Wien and Ackaih (1978) used the term effective pod growth period and actual pod growth period for describing the process of pod shell formation.

Actual pod development period refers to the period from flowering to maturity of the pods whereas effective pod development period is equal to final pod dry weight divided by the rate of increase in dry weight per day in linear phase.

In current investigation, the actual average pod development period for five cowpea genotypes was 18.55 days, whereas effective pod development period was 11.45 days. Thus, the effective period was shorter than the actual pod development period by 7.10 days (Fig. 4). The difference is referred to as lag period. Phule Pandhari (19.50 days), GC3 (11.85 days) and Konkan Safed (8.08 days) had the longest actual pod development, effective pod filling and lag periods, respectively. C152 had shortest actual pod filling (17.25 days) and effective pod filling period (10.99 days), whereas, VCM 8 had minimum lag period (5.95 days).

It would be appropriate to have some concepts regarding the length of some components of pod development period.

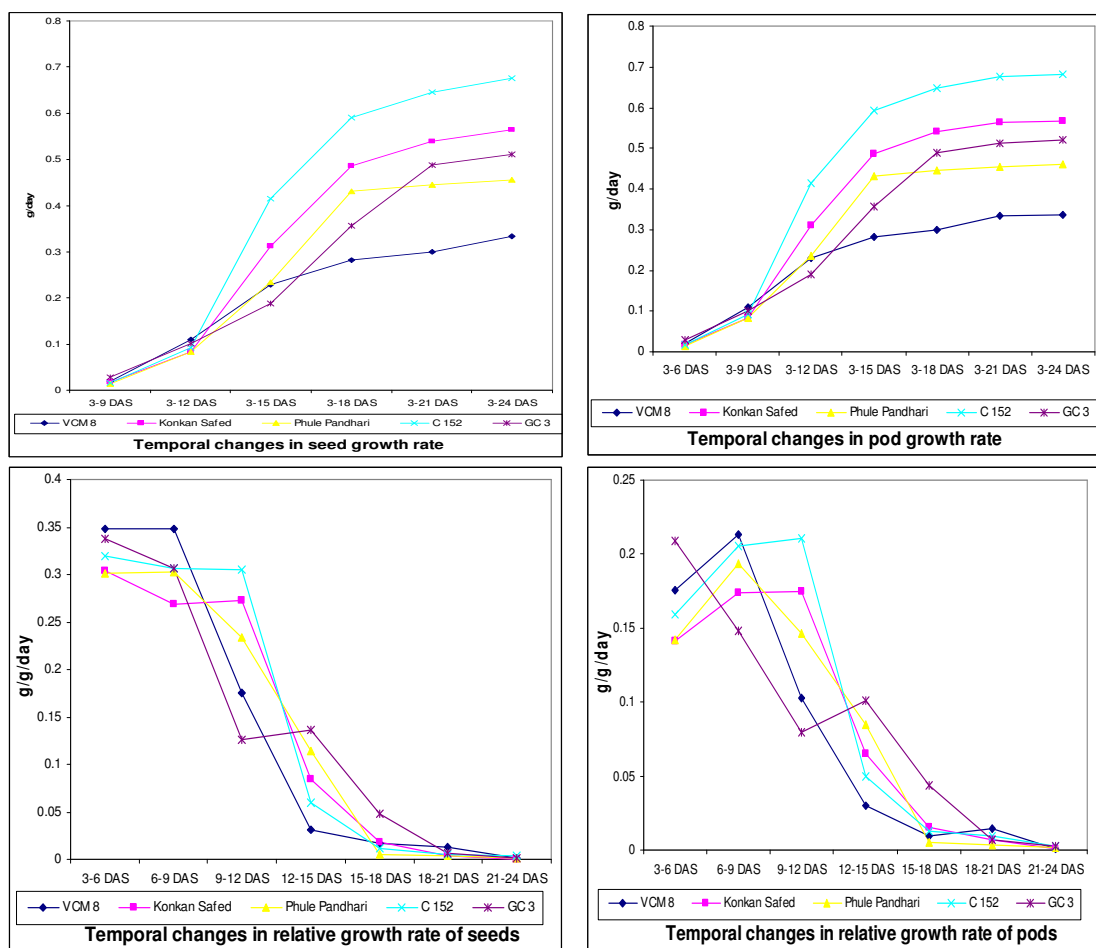


Fig. 3: Periodical changes growth rates and relative growth rate of seed and pod of cowpea genotypes

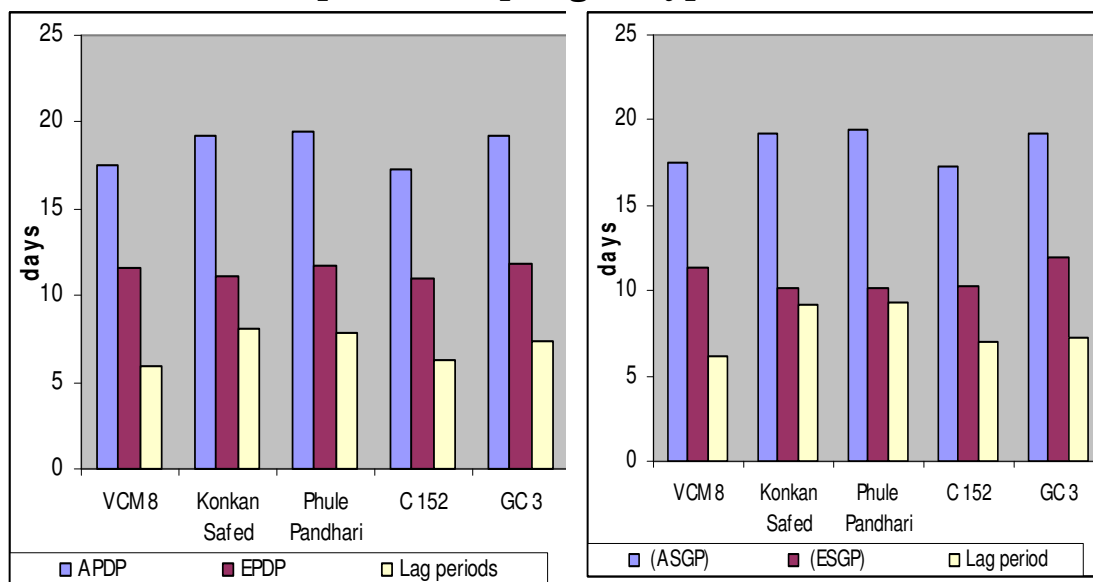


Fig. 4: Actual and effective pod development and seed growth periods among cowpea genotypes

5.2.2. Actual and effective seed growth periods

Chitnis and Jamadagni (1982) estimated the seed filling parameters like actual filling period, actual filling rate, effective filling period, effective filling rate and lag period in cowpea. They proposed that the actual filling period was the sum of effective filling period and lag period.

In current investigation it was noticed that the actual seed development period for five cowpea genotypes was approximately 18.55 days. The effective seed growth period was approximately 11.40 days. Thus there was a difference of 7.15 days in actual and effective seed development. This was the lag period. Every genotype had characteristic features of seed growth period. The longest seed growth period was noticed in Phule Pandhari (19.50 days) followed by Konkan Safed (19.25 days), GC 3 (19.25days), VCM 8 (17.50 days) and C 152 (17.25 days).

The effective seed growth period was longest in GC 3 (11.99 days) followed by d VCM 8 (10.40 days) and C 152 (10.21 days). It was minimum in Konkan Safed (10.09 days).

Lag period was the period during which there was no growth of the grain, hence it would be desirable to have minimum lag period.

In current investigation the minimum lag period was noticed in VCM 8 (6.10 days) followed by C 152 (7.04 days) and GC 3 (7.26 days). The genotype Konkan Safed had longest lag period (21.5 days). Reduction in lag period would lead to shortening the maturity period of the crop. In this context VCM 8, C 152 and GC 3 derived a due attention.

The actual seed growth period appeared to be longer than actual pod development period and effective seed growth period was

longer than effective pod development period. Further, the lag period of seed growth was longer than the lag period of pod growth.

This clearly indicated that the development of pod shell was the first step and occurs rapidly, whereas, seed growth was a second phase and occurs relatively at slower rate in comparison with pod shell growth.

5.2.3. Characters of reproductive growth

Reproductive growth in grain crops is initiated by flowering and a period of pod or seed set. Flower production and seed set is a key phase in the yield production process. The significant growth of economically reproductive part becomes relevance with the time requirement for its full development.

The phenology of crop related with reproductive phase which initiates from the floral bud initiation. The events from the flowering of crop to the development of full matured embryonic seed in terms of period or days are the overall phenology of crop. Therefore, the characters *viz.* days to initiation of floral bud, initiation of first flower, initiation of first pod, 50 % flowering, 50 % podding, last floral bud, last flower, last pod formation, first pod maturity, Last pod maturity were depicted.

In current investigation the average duration of cowpea from sowing to maturity was 78.40 days with maximum duration of 87.00 days in Konkan Safed and minimum of 69.00 days in VCM 8.

The transition from vegetative to reproductive phase was indicated by appearance of flower bud. It required on an average 42.10 days. Bud opened into flowers in next day. The average duration for days to setting of first pod was 44.05 days. Thus, the period from anthesis to the pod setting was only two days. The first pod maturity occurred within 62.60 days from flowering.

On this background it can be stated that, if there is a high degree of synchrony then, the total maturity period calculated as;

Total maturity period	=	Days to first flower bud	+	Period from bud to anthesis	+	Period from flowering to pod set	+	Period from pod set to maturity.
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In current investigation it was

$$78.40 = 42.10 + 1.00 + 1.00 + 34.30$$

Thus, hypothetically in genotypes possessing high synchrony of flowering, the total maturity was achieved within 78.40 days. However, the actual period of maturity in our investigation was 87.00 days which was 8.60 days longer than the hypothetically expected period.

A critical perusal revealed that, the flower bud formation staggered from 42.10 days to 61.90 days. In consequence the flowering was also staggered upto 62.80 days from sowing.

In cowpea, the vegetative growth in terms of emergence and expansion of new branches, formation of new leaves, continued even upto flowering phase. Thus, the reproductive and vegetative growth occurs simultaneously. Usually at the phase of first pod maturity, the vegetative growth stops.

In current investigation first pod maturity occurred in 62.60 days, but last flower bud appeared on 61.90 days. Thus, the flowering continued even at the time of maturity of first pod. Thus, there was an intricate overlapping of flowering and maturity of pods.

These results clearly indicated that, continuous staggered flowering for a period of 43.05 to 62.80 days was one probable reason for extending the duration than the hypothetically expected. In fact the maturity period was extended by 15.80 days than expected period.

A question arises, how this period was extended? The analysis revealed that the last flowering appeared on 62.80 days from the sowing i.e. at the time of first pod maturity. This last flower required 63.70 days for pod setting and set pod at least required 78.40 days for maturity.

Thus, 15 extra days required due to period extended by last flower appearance, last flower set and first pod set and last pod maturity. Hence, the period for pod maturity calculated as;

$$\begin{aligned} \text{Maturity period} &= \text{First bud appearance (d)} + \text{Bud to first flower (d)} + \text{First flower to first pod set (d)} + \text{First pod set to first maturity (d)} + \\ &\quad \text{Staggered flowering period (d)} - \text{Period of difference between last flower to first pod (d)} \\ \text{i. e. maturity period} &= (42 + 1 + 1 + 19 + 20) - 18 = 65 \text{ days.} \end{aligned}$$

5.3. Growth analysis

5.3.1. Dry matter production and it's assimilation in component parts of plant

The pattern of dry matter production and it's distribution into component plant parts has been of phenomenal interest to the research workers engaged in yield analysis. The data on dry matter collected at the different time intervals would give the picture in quantitative terms as regards accumulation and partitioning of the total dry matter among the plant parts throughout the growth period of crop. In view of this, in the present investigation, it envisaged to know the pattern of dry matter accumulation, it's distribution and per cent allocation in component parts of plant.

The pattern of dry matter production and it's distribution into component plant parts are depicted in Fig.5. In the present investigation, dry matter production in roots increased steadily with the advancing age of the crop in all the genotypes. The genotype Konkan Safed found to be promising for dry matter production in roots over other genotype. The rate of dry matter accumulation was

steady between 20 and 40 DAS and increased rapidly upto 60 DAS, thereafter it increased steadily towards maturity (Fig. 5). Deeper root penetration has greater access to stored soil moisture (Smith *et al.*, 1990).

The rate of dry matter production in stem increased steadily upto 60 DAS and became rapid toward maturity in all the genotypes. The rate of dry matter accumulation in Konkan Safed, VCM 8 and GC 3 was in the sequence of rapid, steady and rapid between 20 and 40, 40 and 60 and 60 DAS toward maturity, respectively. However, it was at constant rate in C 152 and Phule Pandhari. Gill *et al.* (1988) reported that dry matter accumulation in leaves and stem was low at initial stage in chickpea. Thandapani and Rao (1986) reported that dry matter accumulation in stem was higher during vegetative stage of the crop in mungbean.

The dry matter accumulation in leaves increased rapidly with the advancing age of crop and was maximum at 40 DAS in all the genotypes. In Konkan Safed, VCM 8 and GC 3, the dry matter accumulation was reduced at 60 DAS due to defoliation of leaves. Thereafter, intermittent rains at later stages resulted in regeneration of tender leaves and increased dry matter towards maturity. However, in Phule Pandhari it was at increased rate and in C 152 maintained at constant rate of dry matter accumulation in leaves at various stages of growth. Vijalaxmi *et al.* (1993) observed that dry matter yield was related to the subsequent rate of leaf production.

The dry matter production in pods was started between 40 and 60 DAS. It was highest in early genotype VCM 8 at 60 DAS. However, it was slower than other genotypes towards maturity. In all the genotypes the rate of pod dry matter accumulation was higher and at constant rate. The genotype GC 3 was found superior

for pod dry matter production. Jagamohan Rao and Singh (1985) reported that pod dry weight went on increasing from 45 days onwards till the maturity.

The rate of total dry matter production was rather slow at initial stage of growth and became rapid from 60 DAS towards maturity in the genotypes except in VCM 8. In VCM 8 it was increased at constant rate at various stages of growth. Reddy *et al.* (1990) reported that total dry weight in green gram and black gram cultivars showed a continuous increase throughout the crop growth period. Bisht and Chandel (1989) observed in soybean plant that, dry matter and its rate of accumulation increased with plant age. Linear increase in dry matter production in groundnut was reported by Kumari and Singh (1990).

The data on per cent allocation of dry matter in component parts of plants in cowpea genotypes revealed that the percent dry matter was higher in stem at initial stage of growth and became declined steadily towards maturity in all the genotypes, whereas, in leaves it was higher between 40 and 60 DAS than at 20 DAS. After 60 DAS, it decreased towards maturity. The per cent dry matter in leaves was rather higher than roots and stem from 60 DAS and steady towards maturity. At the time of maturity, dry matter accumulation was diverted to pod development resulted in higher per cent dry matter in pods. Chaturvedi *et al.* (1980) demonstrated that the pod development was completed in 19 days and the rate of dry matter accumulation during the peak period of growth. Egli *et al.* (1985) suggested that variation in fruit and seed number may be more closely related to variations in the allocation of assimilate between vegetative and reproductive plant parts.

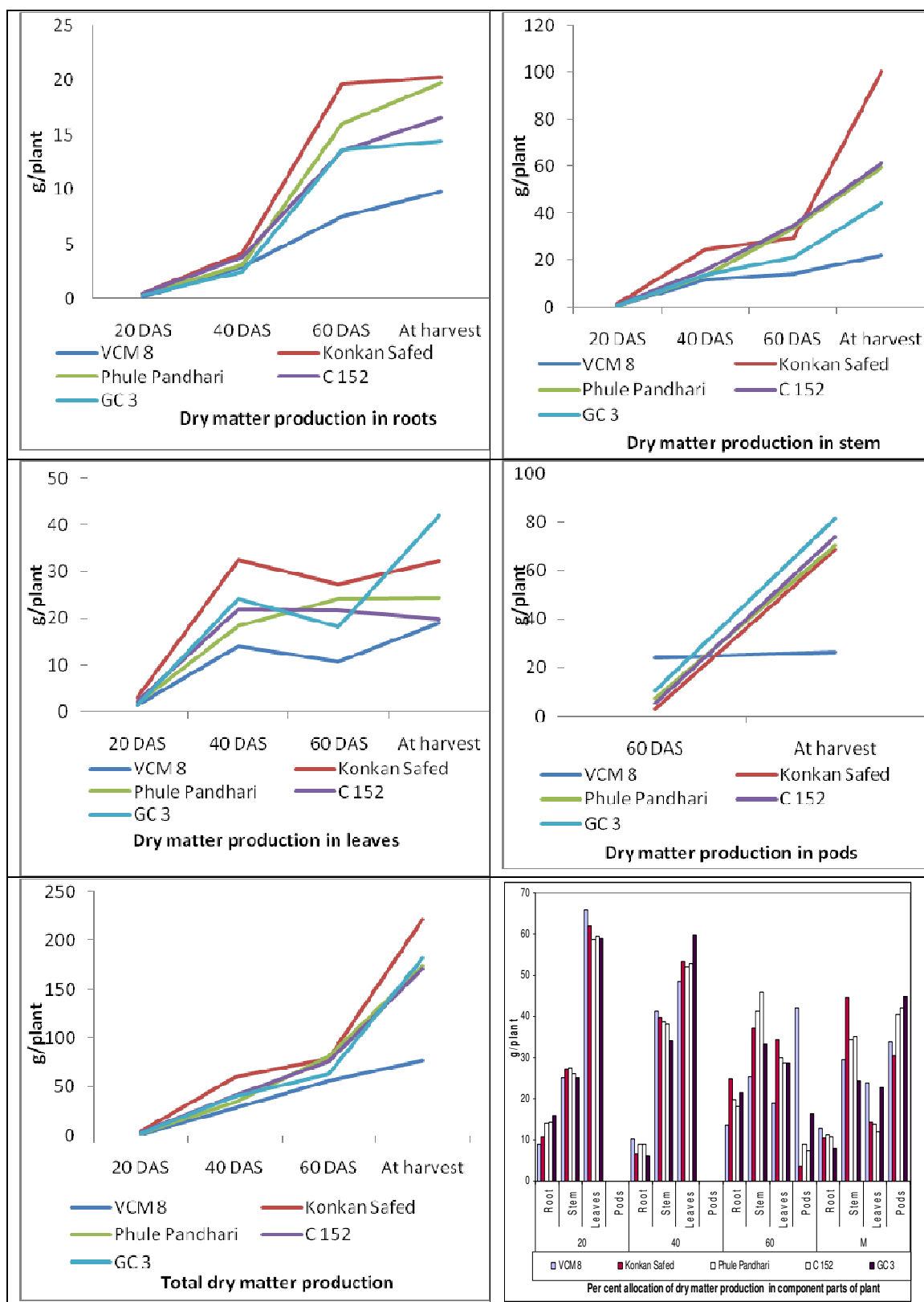


Fig. 5: Dry matter production it's assimilation in component parts of plant in cowpea genotypes at various stages of growth

5.3.2. Growth Parameters

The knowledge of crop physiology through growth analysis technique, which involves tracing the history of growth and identifying the growth and yield factors contributing for yield variation, is a vital tool in understanding the crop behavior. This would be vital to the breeder as well as agronomist in tailoring suitable genotype or management technology for boosting up the growth and yield factors of the crop. Therefore, for a complete analysis of biological yield, it is necessary to investigate crop growth through computation of growth indices such as absolute growth rate (AGR), relative growth rate (RGR), leaf area index (LAI), net assimilation rate (NAR), specific leaf area (SLA), leaf area duration (LAD) and leaf area ratio (LAR). The periodical changes of growth parameters are depicted in Fig. 6.

Briggs *et al.* (1920) defined absolute growth rate (AGR) as daily increment in dry matter over a given period. The AGR gives general idea regarding the pattern of growth at different growth stages. In the present investigation, AGR increased progressively in VCM 8 and Phule Pandhari with the advancing age of the crop. Whereas, in Konkan Safed, C 152 and GC 3 it was decreased between 20-40 and 41 -60 DAS. The rate becomes rapid towards maturity from 61 DAS in all the genotypes.

Blackman (1919) derived concept of relative growth rate (RGR) as an overall measure of rate of increase in dry weight per unit dry weight. Hsu (1977) in berseem and soybean, Shivkumar and Shaw (1977) in soybean reported declined RGR with the advancing age of the crop. The relative growth rate (RGR) influenced by cowpea genotypes at various stages of growth are depicted in Fig 25. In the present investigation, RGR decreased progressively between 20-40

and 41-60 DAS in all the genotypes. Afterwards, it was at constant rate in VCM 8 and Phule Pandhari, increased steadily in C 152 and rapidly in GC 3 towards maturity. Almodares (2007) suggested as plant grows LAI, NAR and RGR increases which consequently increase sucrose content and decrease invert sugar.

Gregory (1926) had given the idea about net assimilation rate (NAR) as the rate of increase in dry weight per unit leaf area. The net assimilation rate (NAR) influenced by cowpea genotypes at various stages of growth are depicted in Fig 26. In the present investigation, NAR was decreased with the advancing age of crop in early maturity group genotype VCM 8. Whereas, in midlate and late maturity group genotypes, it was decreased between 20-40 and 41-60 DAS however it increased rapidly towards maturity. Watson (1958) and Nichiporovich (1964) have reported the decline in NAR with increase in LAI. [Kavurmaci et al. \(2010\)](#) reported large variation in physiological characters between species.

Watson (1947) introduced the concept of leaf area index (LAI) as one of the most important growth parameter. The leaf area index (LAI) influenced by cowpea genotypes at various stages of growth are depicted in Fig 27. In the present investigation, the highest LAI was recorded at 40 DAS in all the genotypes except GC 3. In GC 3 it was higher at 60 DAS. After that, it was decreased rapidly towards maturity due to senescence of leaves and diversion of assimilates in pod development.

The concept of leaf area ratio (LAR) owes its basis to Whitehead and Myrescaugh (1962). The LAR obviates the assumption of linear and quadratic forms of functional relationship between dry weight and leaf area. The leaf area ratio (LAR) influenced by cowpea genotypes at various stages of growth are depicted in Fig 28. In the present investigation, the LAR decreased

progressively with the advancing age of the crop in midlate and late maturity group genotypes. Whereas, it was increased in early maturity group genotype VCM 8 towards maturity due to regeneration of additional young leaves.

Specific leaf area (SLA) is the dry matter production per unit leaf area. The concept developed by Radford (1967) is very useful to understand the ability of leaf to photosynthetic assimilation on per unit basis. The specific leaf area (SLA) influenced by cowpea genotypes at various stages of growth are depicted in Fig 29. In the present investigation, SLA was decreased towards maturity in VCM 8 and C 152, whereas, it increased in GC 3 upto 60 DAS and in Konkan Safed and Phule Pandhari upto 40 DAS. Afterwards it declined towards maturity due to dehiscence of leaves.

The concept of leaf area duration was formulated by Watson (1947) and Gardner *et al.* (1988) on the basis of LAI_1 and LAI_2 represent the leaf area index (LAI) at time T_2 and T_1 , respectively. The leaf area duration (LAD) influenced by cowpea genotypes at various stages of growth are depicted in Fig 30. In the present investigation, LAD was increased between 20-40 and 41-60 DAS and decreased towards maturity in all the genotypes. The higher LAD was recorded in genotype Konkan Safed followed by Phule Pandhari, C 152, GC 3 and VCM 8, respectively.

5.3.3. Physiological parameters

Genotypic differences in the potential grain yield of cowpea have been positively associated with leaf stable carbon isotope discrimination (D), indicating that more productive genotypes had higher internal carbon dioxide concentration in their leaves. A genotype with higher internal carbon dioxide concentration would have higher stomatal conductance in relation to its mesophyll capacity for fixing carbon dioxide. (Hall *et al.*, 1997b; Condon and

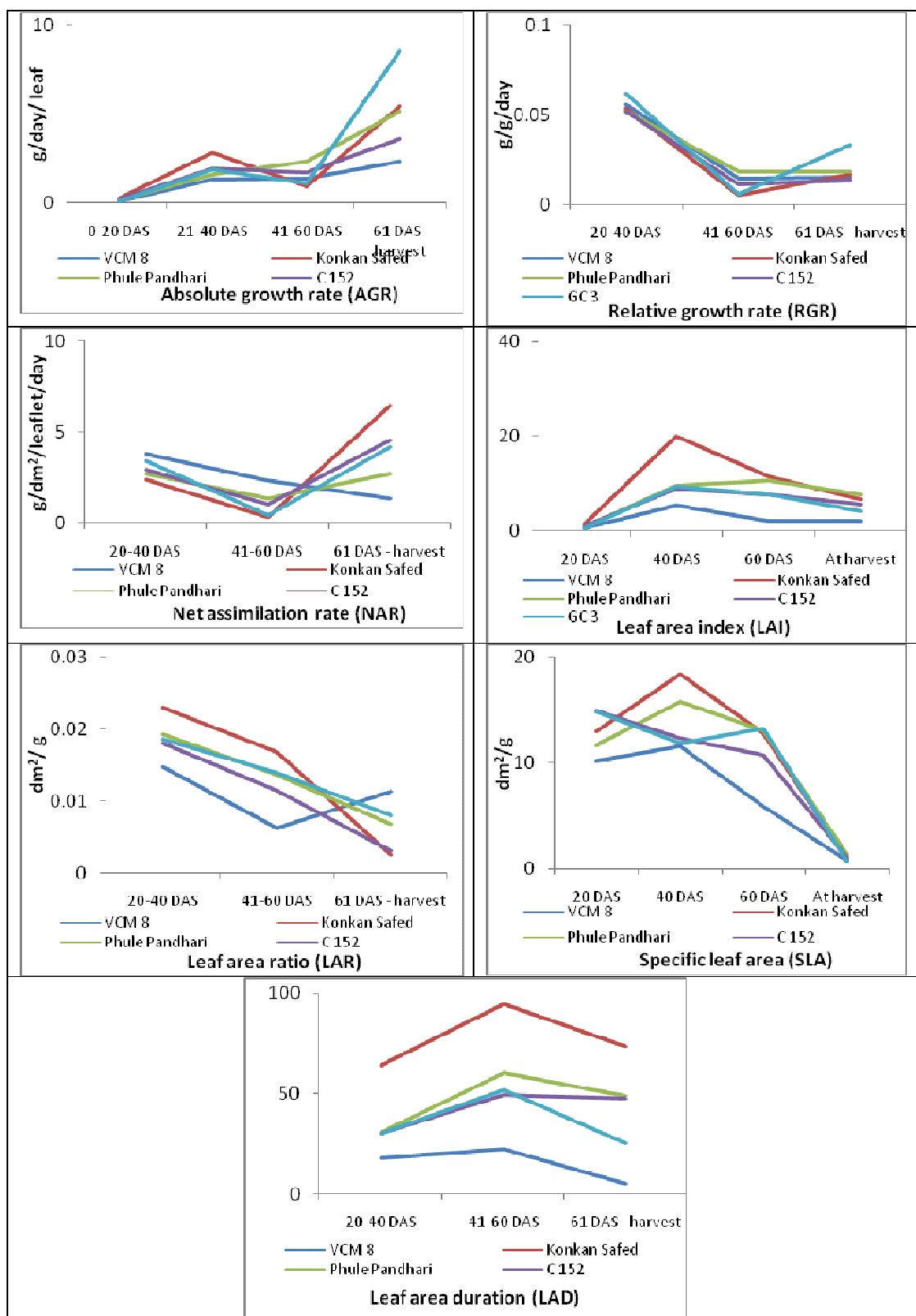


Fig. 6: Periodical changes for growth parameters influenced by cowpea genotypes

Hall, 1997). The photosynthetic process is the plant use solar energy to synthesize organic molecules for carbon dioxide (CO₂) and water (H₂O)

The rate of photosynthesis (P_n), rate of transpiration (T_n), water use efficiency and stomatal conductance influenced by cowpea genotypes at various stages of growth are depicted in fig 7. In the present investigation, the P_n ($\mu\text{mol m}^{-2} \text{sec}^{-1}$) increased between 20 and 60 DAS in Konkan Safed and C 152 which declined steadily towards maturity. In Phule Pandhari and GC 3 it was increased upto 40 DAS which remains constant upto 60 DAS and declined toward maturity. Whereas, in VCM 8 P_n was increase upto 40 DAS and it declined rapidly toward maturity. The genotype, Konkan Safed and C 152 maintained higher values for rate of photosynthesis at various stages of growth. Ravindra *et al.* (2008) mentioned differences in growth and P_n of the cultivars were significant after the onset of reproductive sink. Leaves had maximum rate of photosynthesis for 20 days from full expansion (Littleton *et al.*, 1981). Mythili and Nair (1996) showed a decline in photosynthetic rate was observed after flowering and during pod development in chickpea.

The rate of transpiration (T_n) increased upto 40 DAS which was declined towards maturity in all the genotypes. The genotypes, Konkan Safed, Phule Pandhari and GC 3 had higher rate of transpiration at various stages of growth. It might be due to higher leaf area and leaf area index than other genotypes. Kalpana *et al.* (2003) mentioned that, the determinate genotypes had higher values of photosynthetic rate (P_n), transpiration rate (TR), stomatal conductance.

The water use efficiency increased progressively in C 152, Konkan Safed and Phule Pandhari with advancing age of the crop,

whereas in VCM 8 it was comparatively low values than other genotypes which was increased upto 60 DAS and declined towards maturity. In GC 3 the rate of water use efficiency becomes higher at initial stages however, it was reduced towards maturity. Patel *et al.* (2008) showed variability for water expense efficiency of cowpea genotypes. Abscissic acid content was positively correlated with water use efficiency, biomass and leaf area (Ismail *et al.*, 1994). Hendrik Poorter *et al.* (1994) reported high rate of transpiration per unit leaf area had a higher C_i/C_a ratio and lower water use efficiency of photosynthesis the in herbaceous species.

The stomatal conductance increased upto 40 DAS in Konkan Safed, GC 3 and VCM 8 and declined rapidly toward maturity. In C 152 and Phule Pandhari it reduced steadily toward maturity. The genotypes, Konkan Safed and VCM 8 maintained higher magnitude of stomatal conductance as compared to other genotypes. The results were in accordance with Kalpana *et al* (2003). Ludlow *et al.* (1985) mentioned that the stomatal conductance and leaf photosynthetic rate of legume species in the field are insensitive to water deficit.

5.4. Morphological characters

5.4.1. Vegetative growth and source

Before embarking on any selection programme to develop high yielding types, it is imperative to have knowledge of the magnitude of variability and inter-relationship among different characters in the material for the characters, which we want to improve. The vegetative phase governs the overall phenotypic expression of the plant and prepares the plant for next important reproductive phase. The plant height, branches and leaves, all these parts constitute vegetative phase and perform specific functions.

The root and shoot growth increased with advances in maturation [Burries *et al.*, 1973] which was in coincidence with stages of dry weight of pod / seed and seed germination. In the present investigation, it was observed that the plant height increased progressively with the advancing age of the crop. The genotypes, Phule Pandhari, C 152 and Konkan Safed come under tall group, GC 3 under midtall and VCM 8 under dwarf group (Fig 8). Tikka and Asawa (1981) observed that the yield was correlated with plant height in cowpea.

The number of primary branches per plant increased continuously with the advancing age of the crop. The rate of increase of primary branches per plant was initially rapid. Thereafter, it remained constant. Phule Pandhari had higher number of branches at harvest than other genotypes (Fig 8). Naidu *et al.* (1996) reported that, mean number of branches, clusters, pods/plants, seeds/pod, seed weight and seed yield were found high in determinate types while plant height and pod length were found high in indeterminate types in cowpea.

The plant derives food and energy for its metabolic activities from a source. The primary function of leaves is carbon assimilation. Thus, leaf is the photosynthetic apparatus of the plant. In the present investigation, it observed was that the number of leaves per plant increased progressively upto 60 DAS in midlate and late maturity group genotypes, whereas in early genotype, VCM 8 it increased upto 40 DAS. Thereafter, number of leaves decreased towards maturity due to leaf senescence (fig 8).

Watson (1956) concluded that, yield was dependent on size, efficiency and duration of photosynthetic system and hence, leaf area and leaf area duration contributed more to biological yield. In the present investigation, the leaf area increased progressively with

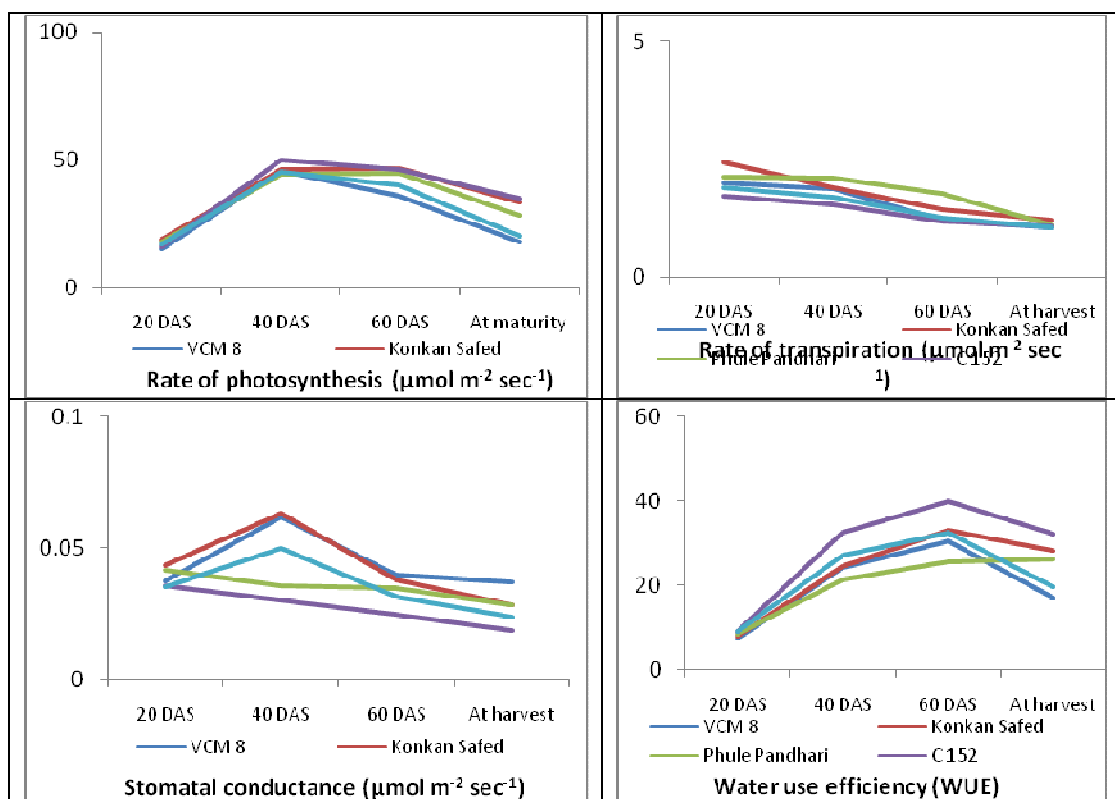


Fig.7: Periodical changes for physiological parameters influenced by cowpea genotypes

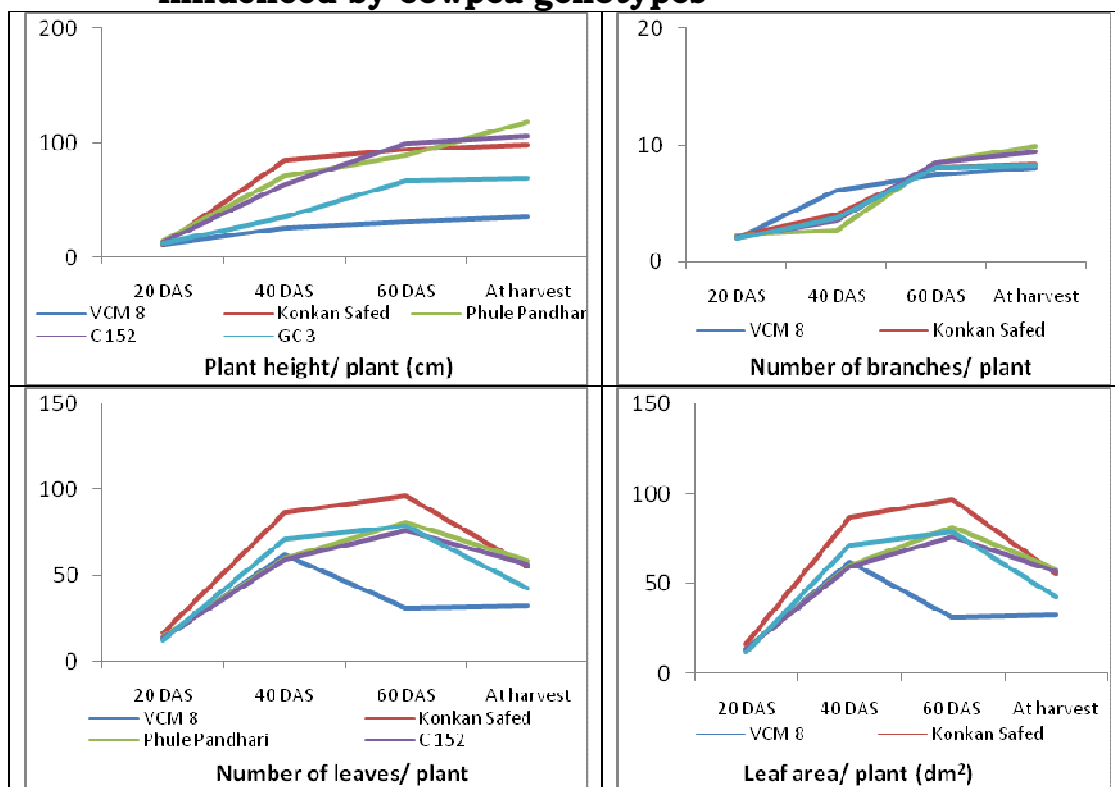


Fig.8: Periodical changes for vegetative growth and source influenced by cowpea genotypes

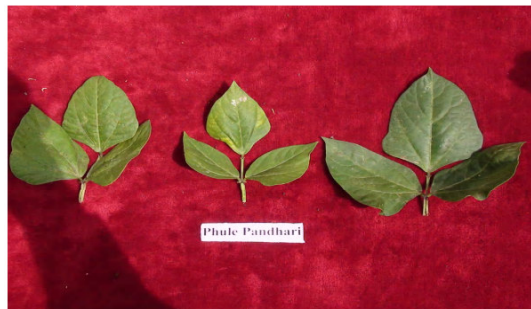


Plate 4: Genotypic variation in leaf size

advancing age of the crop upto 60 DAS in Konkan Safed, Phule Pandhari, C 152 and GC 3, whereas in VCM 8 it increased upto 40 DAS. Thereafter, it was lowered down due to leaf senescence (Fig 8). Shinde and Saraf (1991) noted the positive and significant correlation of seed yield with leaf area in chickpea.

5.4.2. Generative Growth and Sink Capacity

Yield improvements have been achieved through directional selections for yield contributing traits (Akbar and Kamran, 2006). Pods, seed yield and 100 seed weight have been reported among the prominent grain yield determinants of cowpea (Brolmann and Stoffella, 1986; Siddique and Gupta, 1991). They have been found to have reliable predictability on grain yields in grain legumes (Singh and Malhotra, 1970; Narsinghani *et al.*, 1978; Dani, 1979).

In pulses, the pods/plant, seeds/per pod and seeds/ plant have direct influence on the grain yield. In the present investigation, the number of pods/ plant was ranged between 13.35 and 15.95, seeds/ pod between 11.25 and 11.99 and seeds/ plant between 150.20 and 192.52. The treatment differences were statistically significant indicating wide range of variation for these traits. The genotype, C 152 maintained higher number of pods/ plant, seeds/pod and seeds/ plant over other genotypes. Khan and Stofella (1985) concluded that pod/plant was single component related to seed yield while seeds/ pod and seed size provided little additional indication of crop yield in cowpea. Oliveira *et al.* (1990) reported a positive correlation between number of pods per plant and seed production in cowpea.

The treatment differences were statically significant for seed yield per plant and 100 seed weight in this investigation. Konkan Safed had a bold seed size followed by GC 3 and VCM 8. However,

the small seeded genotype, C 152 recorded higher seed yield per plant followed by GC 3 and Phule Pandhari. It is an important to note that the genotype, GC 3 even though bold seed size it maintained higher seed yield per plant. Bhaskarain *et al.* (1980) reported that in the high yielding parents of cowpea, pods per plant and 100 seed weight were most important yield contributing characters.

Yield is compound character and is sum of the contributions made by a number of physiological characters. To the Plant Scientists, it is the net economic gains from the source and sinks capacity. In the present investigation, the treatment differences for seed yield were statistically significant. The genotype, C 152 maintained higher levels of seed yield per plot and per hectare followed by Phule Pandhari and Konkan Safed. Amongst these, C 152 and Phule Pandhari had higher pods per plant and number of seeds per pod, whereas, Konkan safed was a bold seeded genotype. Sarkar (1990) reported that plant height, pod number per plant and total dry matter production (TDMP) exhibited positive significant association with grain yield in pea.

Total biomass is the total dry matter production capacity of plant within its life cycle. In the present investigation, the treatment differences were statistically significant for dry fodder yield per plot, total biological yield per plot and harvest index (%). In the present investigation, higher dry fodder yield per plot and total biological yield was maintained by C 152, Phule Pandhari and Konkan Safed. However on the basis of economic yield and total biological yield, the early maturing genotypes, VCM 8 and GC 3 recorded highest harvest index (%). Therefore, the genotypes, VCM 8 and GC 3 were found to be beneficial for breeding programme in boosting up the seed yield whereas other genotypes might be considered for fodder

yield heterosis programme. Mokhtassi-Bidgoli *et al.* (2007) reported higher dry matter accumulation, HI, seed weight and 1000-seed weight were found to be closely related to high yielding genotypes.

5.5. Bio-chemical parameters

5.5.1. Crude protein

Cowpea is an important source of protein in developing countries (Dovlo *et al.*, 1976). In the present investigation, the crude protein content in seeds harvested at 9 DAF was very low. However, at 12 days it increased rapidly and achieved maximum crude protein content at 15 DAF. Thereafter it remains constant with the advancement of the crop (Fig. 9). The crude protein content of 21 DAF was ranged between 23.07 and 24.48 per cent. Naik *et al.* (2000) reported that, crude protein ranged from 17.20 to 29.90 per cent in cowpea. Ajeigbe *et al.* (2008) found variations in protein content among cowpea varieties (21.3-26.9%). Henshaw (2008) showed significant variation of crude protein had range values of 20-27%. Sebetha (2010) studied the protein content of green cowpea pods which ranged from 17.9 to 25.1%.

5.5.2. Carbohydrates

5.5.2.1. Reducing sugars

Sugars with reducing property are called reducing sugars (glucose, galactose, lactose and maltose). The Nelson-Somogyi method is one of the widely used methods for the quantitative determination of reducing sugars. Nelson (1944) reported a colorimetric modification of a micro copper titrimetric method developed by Somogyi (1937). In the present investigation, the genotypic differences were non-significant for reducing sugar. The reducing sugars in seed increased with advanced stages of seed growth (Fig. 9). Singh and Singh (1985) determined reducing sugars

from fruit coat, seed coat and cotyledons separately which is 1.15, 1.35 and 2.40 mg/ 100 mg, respectively.

5.5.2.2. Total carbohydrates

The basic units of carbohydrates are the monosaccharides which cannot be split by hydrolysis into simpler sugars. In the present investigation, the carbohydrate content estimated from the seed harvested at 9, 12, 15, 18 and 21 days after flowering. It increased steadily with the advancement of the crop (Fig. 9). The genotypes, C 152, Konkan Safed and Phule Pandhari were significantly superior for carbohydrate content. Ajeigbe *et al.* (2008) examined variation in physico-chemical properties of seed of selected improved varieties of cowpea and reported the ranges of protein (21.3 - 26.9%) and carbohydrates (63.37 - 69.56%).

5.5.2.3. Starch content

Starch is an important polysaccharide. It is the storage form of carbohydrate in plants abundantly found in roots, tubers, stems, fruits and cereals. Starch, which is composed of several glucose molecules, is a mixture of two types of components namely amylose and amylopectin. In the present investigation, the starch content estimated from the seeds harvested at 9, 12, 15, 18 and 21 days after flowering which was more or equal concentration at all the stages of seed growth (Fig. 9). The genotypes VCM 8 and GC 3 exhibited higher starch content. Singh and Singh (1985) determined starch content from fruit coat, seed coat and cotyledons separately of cowpea seed which is 18.20, 12.55 and 20.66 mg/ 100 mg, respectively.

5.5.3. Fat content

Ajeigbe *et al.*, (2008) studied the variation in physico-chemical properties of seed of selected improved varieties of cowpea for fat

content (1.2-1.8%). In the present investigation, fat content in seeds increased progressively upto 18 DAF i.e. seed maturation (Fig. 9). The genotypes, Phule Pandhari, Konkan Safed and C 152 recorded significantly higher fat content than VCM 8 and GC 3. Henshaw (2008) in his study recorded the range of fat content in cowpea seeds between 0.6 and 1.0%.

5.5.4. Fiber content

Cowpea varieties with high crude fibre would be desirable in making meals for diabetic patients. In the present investigation, the fiber content was higher at initial stages. However, it declined with developing stages and increased with the seed maturation (Fig. 9). Fiber content was ranged between 4.61-5.31%. High positive correlations (0.86) were observed between the content of fat and crude fiber (Ajeigbe, 2008).

5.5.5. Vitamin content

5.5.5.1. Niacin content

Cowpea enhances the quality by the synergistic effect of high protein, lysine and methionine and high energy from the starchy food (Singh *et al.*, 2003). Because of its high protein, vitamins and minerals contents, it impacts positively on the health of women and children (Ajeigbe, 2008). There was a slight increase in niacin content towards seed maturity (Fig. 10). In the present investigation, niacin content ranged between 2.01 and 2.67 mg/100g.

5.5.5.2. Thymine content

Because of high protein, vitamins and minerals contents, cowpea impacts positively on the health of women and children. Ajeigbe (2008) showed that for 2 - 5 year old children, in the wet season cowpea and other legumes together contributed 35% of

thiamine intake, 31% of protein, 24% of iron, 21% of niacin, 16% of energy and riboflavin and 13% of calcium. In the present investigation, thymine content was increased with advancing the seed growth upto 18 DAF and remains constant at 21 DAF (Fig. 10). The thymine content ranged between 0.89 and 1.00 mg/ 100 g.

5.5.5.3. B-carotene

The *B*-carotene in the present investigation was ranged between 27.33 and 30.22 mg/100 g. It revealed that the cowpea seeds are the rich source for *B*-carotene. At initial stage of seed development the *B*-carotene was low which increased rapidly between 9 and 15 DAF. Afterwards, it increased steadily towards seed maturation (Fig. 10).

5.5.6. Chlorophyll content in pod wall.

The chemical compounds most important in this conversion of light energy to chemical energy are the pigments that exist within the chloroplast (B. Glass, 1961). The chl 'a' and 'b' covers majority of the portion of chloroplast. Price and Hedley (1980) determined activities of phosphoenolpyruvate (PEP) carboxylase and ribulose-1, 5-bisphosphate (RuDP) carboxylase in the developing pod walls of six genotypes of *Pisum sativum*. He stated that RuDP carboxylase activity correlated with chlorophyll concentration.

The chlorophyll 'a' content in pod walls influenced by cowpea genotypes at various stages of growth are depicted in Fig 10. On an average, the chlorophyll 'a' content of pod wall decreased with the advancing age of the crop. The genotype, C 152 had higher content of chlorophyll 'a' was at 6 and 12 DAF. The results revealed that the rate of photosynthesis might be reduced with pod maturation and synthesis of chlorophyll synthesis becomes ceased. The initial chlorophyll 'a' synthesis was higher in GC 3, whereas, VCM 8 exhibited lower rate of initial chlorophyll 'a' synthesis in pod wall.

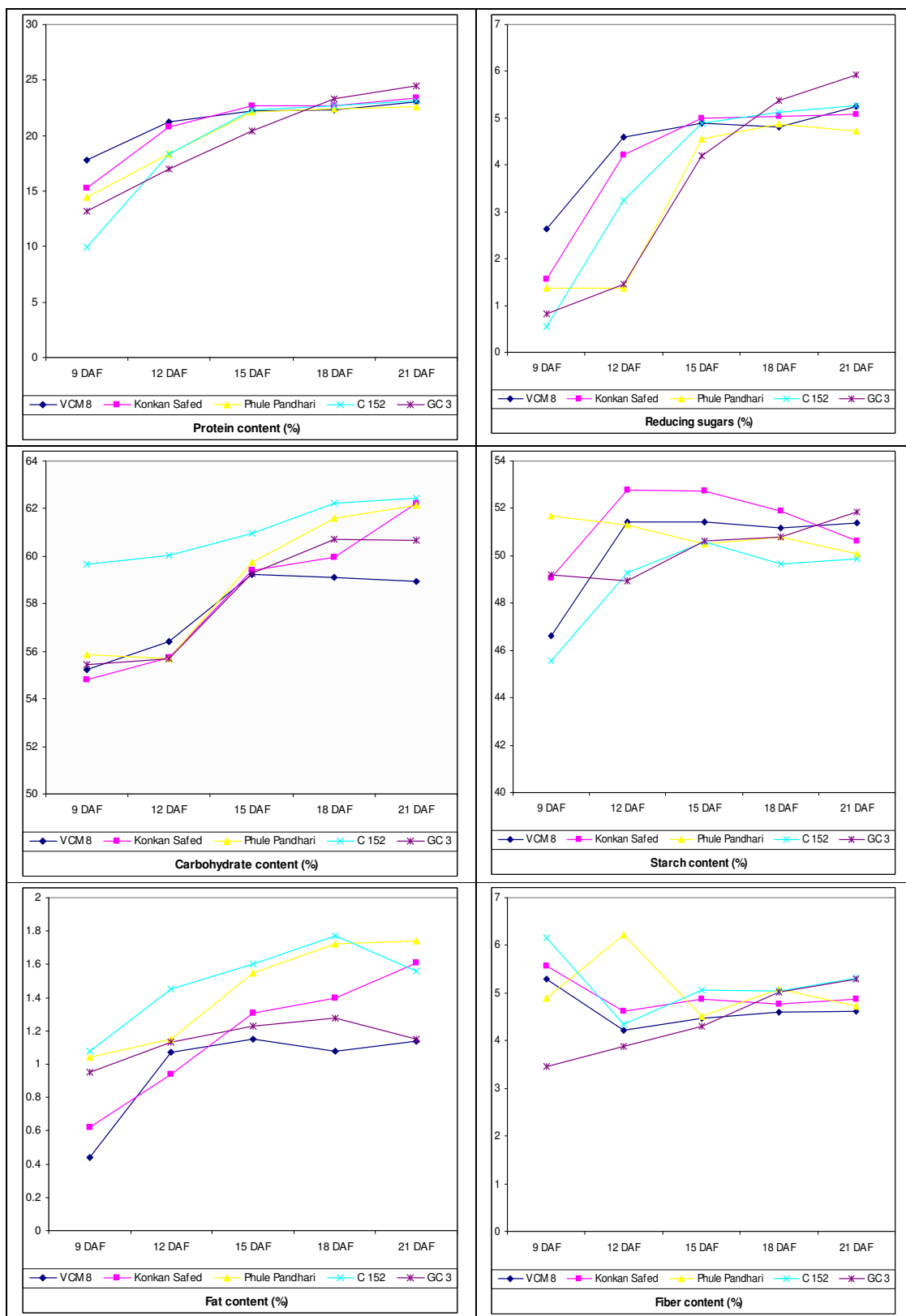


Fig 9. Periodical changes for biochemical parameters influenced by cowpea genotypes

The chlorophyll 'b' content in pod walls influenced by cowpea genotypes at various stages of growth is depicted in Fig 49. On an average, the chlorophyll 'b' content of pod wall decreased with the advancing age of the crop. There was a higher rate of chlorophyll 'b' content in Konkan Safed and C 152 at 6-9 to 9-12 DAF over initial stage, respectively. It declined towards pod maturation due reduction in photosynthetic rate with advanced age of the crop. The genotypes, GC 3 and Phule Pandhari had higher and lower rate of chlorophyll 'b' synthesis, respectively.

The total chlorophyll content in pod walls influenced by cowpea genotypes at various stages of growth are depicted in Fig 10. The chlorophyll content of pod wall decreased with the advancing age of the crop. The genotypes, VCM 8, Phule Pandhari and C 152 exhibited higher chlorophyll content at 6 DAF. C 152 exhibited higher chlorophyll synthesis at 12 DAF. The genotypes, GC 3 and Konkan safed exhibited higher rate of chlorophyll synthesis. The positive b_0 values in polynomial as a good fit for chlorophyll indicated that the initial rate of synthesis was higher than that of advanced stages. The chlorophyll concentrations in pod wall decline differentially with development (Furbank, 2004).

5.6. Morphological characterization

In the present investigation, in all 14 morphological characters were studied in five cowpea genotypes. These genotypes were categorized into different group/ states as per the National Test Guidelines for DUS testing. From the results it is seen that some of the genotypes are very distinct from the other genotypes in one or two morphological characteristics.

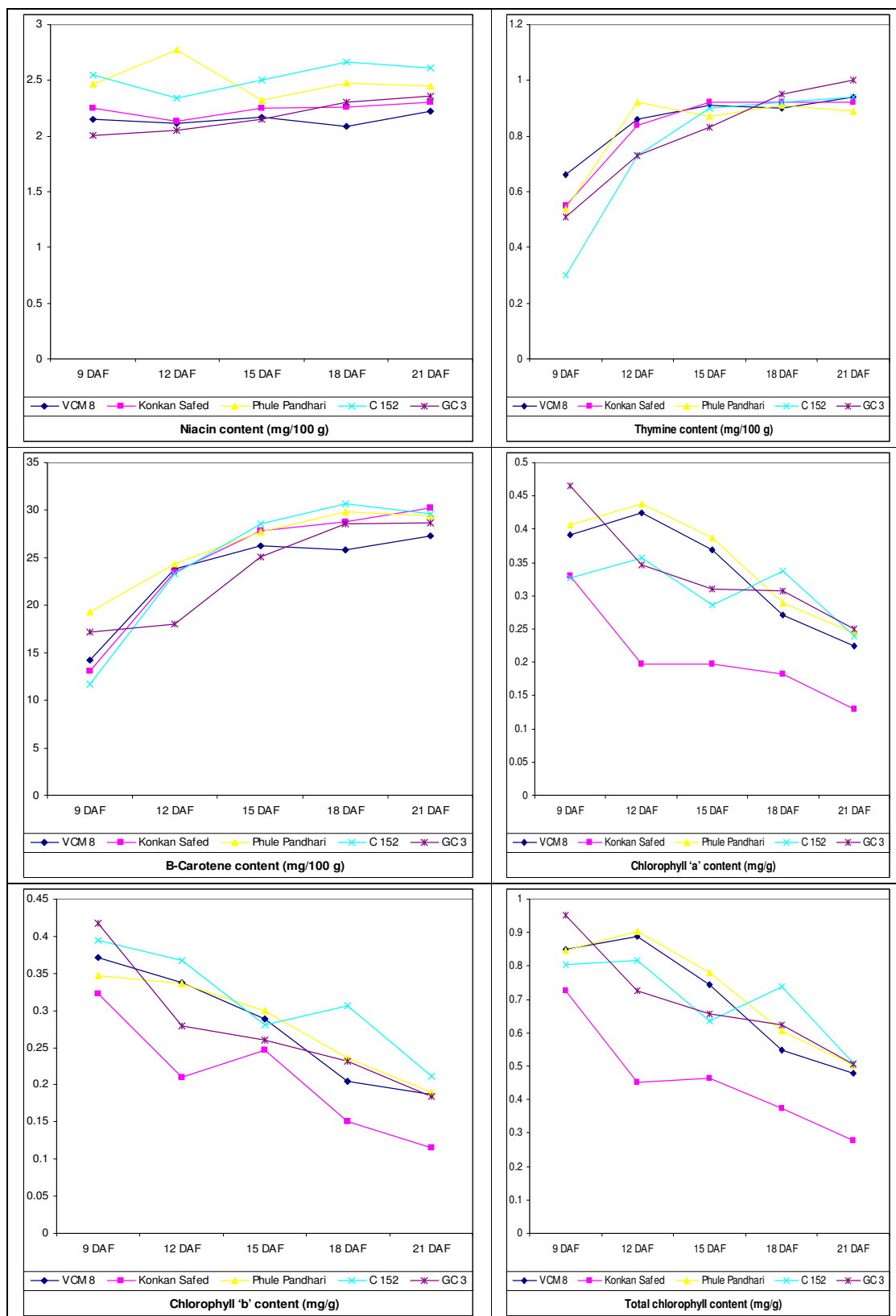


Fig 10. Periodical changes for vitamin content in seed and chlorophyll content in pod wall influenced by cowpea genotypes

The genotype, VCM 8 and GC 3 had very distinct dark green and light green colour pigmentation in seedling and leaflets, respectively maintaining very good early plant vigour. VCM 8 had a determinate type of growth habit while GC 3 had indeterminate type of growth habit. Both genotypes have profuse branching and dark green foliage colours. VCM 8 had dark green stem colour and GC 3 had purple stem colour. Both the genotypes have medium leaflet margin light blue coloured flowers. Pod size was smaller in VCM 8, whereas, it was high in GC 3. Both the genotypes possess the medium seed size, elongated seed shape, smooth seed surface texture and creamy white seed colour.

The genotype Konkan Safed was very contrast than the other genotype, in respect of flower colour i.e. white, milky white seed colour and oblong type of seed shape. Seed size was also very high than other genotypes. It maintained light green pigmentation on seedlings, leaflets, foliage and stem. It had profuse branching, high leaf margin, high pod size and smooth seed surface texture.

The genotypes, Phule Pandhari and C 152 were distinct in respect of stem colour and pod sizes which recorded light green and dark green stem colour and medium and high pod size at maturity, respectively. The rest of the characters were similar for both the genotypes. They have dark green pigmentation on seedling and leaflets, good early plant vigour, indeterminate type of growth habit, medium branching habit, green foliage, high leaflet margin, flower colour is dark blue, small seed size, elongated seed shape, smooth seed surface texture and red coloured seeds.

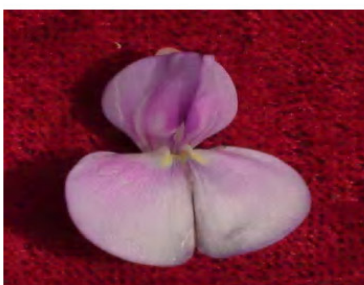
VCM 8**Konkan Safed****Phule Pandhari****C 152****CC 3**

Plate 5. Genotypic variation in size, weight and colour of flower

5.7. Crop model

A successful use of modeling techniques for interpretation of biological processes has been attempted by some workers (Hesketh and Jones, 1978).

Model can be either quantitative or qualitative. The mathematical tools can be used as heuristic model for describing the phenomenon of various biological events. Such heuristic models have been used (Hackett, 1973; Waggoner, 1969; Ludlow and Wilson 1971; Erickson, 1976 and Hesketh, 1963) for predicting photosynthesis, carbon and nitrogen metabolism (Hesketh and Jones, 1978), leaf and light interception, leaf expansion, leaf growth as well as leaf senescence.

In current investigation, the polynomial fitted for growth of seeds, pod shell and pod development has explained the phenomenon adequately. Usually, the value of coefficient of determination (R^2) is taken as an indication for assessing the feasibility of using a particular polynomial for explaining the phenomenon. If R^2 value is more than 0.8, the model is best fitted.

In this context the cubic model appeared to be best for seed and pod development as these polynomials are based on the periodical data of seed growth generated from five divergent genotypes of cowpea. They can be used as heuristic model for understanding the phenomenon and planning of research programme. Thus a seed growth in terms of length, breadth, width and pod shell growth in terms of volume, length, girth appeared to be highly predictable and the genetic variations can be predictably studied in cowpea.

The DSSAT (Decision Support System for Agrotechnology Transfer) is a computational system that includes a data base

management system, crop models, and application programs. There are no reliable models for cowpea in the literature.

This CROPGRO-cowpea model uses the codes and structure of as described by Tsuji *et al.* (1994) and Boote *et al.* (1998a, 1998b). The input parameters that define cultivar and ecotype files (Table 74), species file (Table 75) and Source and sink parameters (Table 76) were utilized for the development of cowpea model.

Implications of the present investigation on future work on pod ontogeny in cowpea

The present investigations have clearly brought out the importance of reproductive growth approaches in locating the causes for yield differences in cowpea. The information on pod and seed growth, pod development, effective and actual pod/ seed development periods, lag periods, characters of reproductive growth, dry matter production and it's distribution in component parts of plants, growth analysis, physiological parameters, vegetative growth and source, generative growth and sink capacity, chlorophyll content of pod wall and proximate composition of seeds influenced by cowpea genotypes has been gathered. Such information based on the growth analysis concept, will go a long way in obtaining the desirable results better and earlier, besides providing ideas for further thinking and investigation. Such a purposeful work in cowpea was needed to understand and to increase the yield levels in this crop by shortening the reproductive phases.

Table 77. CROPGRO Cowpea model

Parameters	Values
1. Cultivar file	
A. Pod development (Bastos et al, 2002)	
Time between first flower and maximum pod length, girth and diameter	15 days
Time between first flower and maximum seed length and diameter	15 days
Time between first flower and maximum pod volume	15 days
Time between first flower and maximum seed volume	12 days
Time between first flower and fresh weights of pod, pod wall and seed	15 days
Time between first flower and constant dry weight of pod, wall and seed	21 days
B. Characters of reproductive growth (Bastos et al, 2002)	
Time between emergence and floral bud formation	42 days
Time between emergence and first flower	43 days
Time between first flower and first pod	2 days
Time between first flower and first seed	4 days
Time between first flower and last flower	20 days
Time between first flower and last pod formation	21 days
Time between first flower and first pod maturity	20 days
Time between first flower and last pod maturity	36 days
C. Seed and pod filling rate (Wien and Ackaih, 1978)	
Days for maximum seed and pod growth rates	6-21
Maximum relative growth rates of pod (DAF)	6-9
Maximum relative growth rates of seeds (DAF)	3-6
Actual pod development periods (APDP)	36 days
Effective pod development periods (EPDP)	20 days
Lag periods for pod development	16 days
Actual seed growth periods (ASGP)	35 days
Effective seed growth periods (ESGP)	19 days
Lag periods for seed growth	16 days
2. Ecotype file	
Time between planting and emergence	4 days
Time between emergence and first true leaf	5 days
Time between physiological maturity and overall maturity	5 days
The maximum ratio of seed/ (seed + Shell) at maturity	76 %
3. Growth analysis	
A. % allocation of dry matter production (Descriptive model)	
Root	11
Stem	34
Leaves	17
Pods	38

Table 77. Contd...

Parameters	Values		
B. Growth Parameters (Explanatory model)			
Absolute growth rate (g/day/plant) - 61 DAS to maturity	4.99		
Relative growth rate (g/g/day) - 61 DAS to maturity	0.0194		
Net assimilation rate (g/dm ² /leaflet/day) - 61 DAS	3.84		
Leaf area index (LAI) at 40 DAS	10.69		
Leaf area ratio (dm ² / g) at 41-60 DAS	0.0124		
Specific leaf area (dm ² /g) at 40 DAS	13.98		
Leaf area duration (days) at 41-60 DAS	55.75		
C. Physiological Parameters (Simulation models).			
Rate of photosynthesis (µmol m ⁻² sec ⁻¹) at 40 DAS	46.42		
Rate of transpiration (µmol m ⁻² sec ⁻¹) at 40 DAS	1.83		
Water use efficiency (WUE) at 40 DAS	25.98		
Stomatal conductance (µmol m ⁻² sec ⁻¹) at 40 DAS	0.0482		
D. Bio-chemical parameters parameters (Deterministic models)			
Protein content in seeds (%)	22-25		
Reducing sugar content in seeds (%)	4-6		
Carbohydrate content in seeds (%)	58-63		
Starch content in seeds (%)	49-52		
Fat content in seeds (%)	1.14-1.74		
Fat content in seeds (%)	4.60-5.35		
Niacin content in seeds (mg/100 g)	2.20-2.70		
Thymine content in seeds (mg/100 g)	0.80-1.00		
Vitamin A content in seeds (mg/100 g)	27-31		
Chlorophyll content in pod wall (mg/g)	3 DAF	6 DAF	9 DAF
Chlorophyll 'a'	0.3838	0.3528	0.3098
Chlorophyll 'b'	0.3707	0.3061	0.2751
Total chlorophyll	0.8452	0.7577	0.6564
4. Source-sink parameters			
A. Vegetative growth and source (Mechanistic models)			
Plant height (cm)	69-119		
Number of branches plant ⁻¹	8-9		
Number of leaves plant ⁻¹	60-90		
Leaf area (dm2) plant ⁻¹	150-600		
B. Generative Growth and Sink Capacity (Deterministic models)			
Number of pods plant ⁻¹	13-16		
Seeds pod ⁻¹	11-12		
Seeds plant ⁻¹	150-200		
Seed yield plant ⁻¹ (g)	10-15		
100 seed weight (g)	8-11		
Seed yield (kg/ha)	900-1300		
Harvest index (%)	32-53		

The information on integrated history of events in pod development constructed from empirical models for such components gives an idea about rate of pod and seed growth. The pod wall associated with major metabolic and biochemical reactions as reservoir for seed development. Therefore, the growth phases of pod shell and seed were the relevant characteristics for calculating the pod/ seed growth rates/ periods. The periodic studies and events related with growth and use of polynomials constructed from the data on series of observations is an established practice in physiological studies. Such polynomial curves fitted with adequate accuracy can summarize the growth data in a convenient way.

The phenology of crop related with reproductive phase which initiates from the floral bud initiation. The events from the flowering of crop to the development of full matured embryonic seed in terms of period or days are the overall phenology of crop. The periods for each event (cultivar file) and differences within the events (ecotype file) can be measured, were utilized for the development of CROPGRO-cowpea model.

The pattern of dry matter production and its distribution into component plant parts has been of phenomenal interest to the research workers engaged in yield analysis. The data on dry matter collected at the different time intervals would give the picture in quantitative terms as regards accumulation and partitioning of the total dry matter among the plant parts throughout the growth period of crop.

The growth analysis technique involves tracing the history of growth and identifying the growth and yield factors contributing for yield variation, is a vital tool in understanding the crop behavior. The physiological characters are the constructive processes of carbon compounds which act as reserve foods of plant parts

particularly in seeds and fruits. This would be vital to the breeder as well as agronomist in tailoring suitable genotype or management technology for boosting up the growth and yield factors of the crop.

The crop behaviour related with their vegetative growth and source ability as well as generative growth and sink capacity were directly correlated with the yield ability of crop. Therefore, the major yield contributing characters from these aspects were covered in the present investigation.

All these would add to the better understanding of the yield relations to obtain maximum yield through manipulation of the inner functions of outer environment. It would thus benefit the future research workers through providing material for further investigation in better understanding plant growth and yield complex in cowpea.

6. SUMMARY AND CONCLUSION

The investigation entitled “Pod Ontogeny in Cowpea [*Vigna unguiculata* (L.) Walp]” was undertaken at Pulses Improvement Project, Mahatma Phule Krishi Vidyapeeth, Rahuri, Dist.: Ahmednagar during seasons of *Kharif* 2009 and 2010.

Five diverse cowpea varieties *viz.* VCM 8 (determinant type), Konkan Safed, Phule Pandhari, C 152 and GC 3 (indeterminate types) were utilized for the experimental purpose. The experiment was conducted with following objectives.

1. To investigate various events from setting of floral bud till maturity of pods in context of various growth characters in cowpea varieties
2. To estimate pod and seed filling rates in context of length of pod and size of seeds in cowpea varieties
3. To investigate total, actual and effective filling periods and their relation with actual and effective filling rates in cowpea varieties
4. To assess growth rate and photosynthetic rate in cowpea
5. Analysis of starch, carbohydrates and protein content during pod development in cowpea

The soil of experimental plot was medium black with good water holding capacity and pH ranging from 7.0 to 7.5. The soil was found to be medium in available nitrogen, low in available phosphorus and medium available potassium.

The stage of occurrence of flowering bud was monitored very critically for each genotype. At anthesis, 500 flowers of uniform age in each genotype were tagged on the same day. Ten flowers/ pods developed from them were detached from each genotype in each replication at three days interval from the day of tagging. The data on fresh weight, dry weight, length, breadth, girth and volume of flowers/ pods at each sampling were recorded carefully.

The observations on phenological studies (Juvenility), morpho-physiological characters, generative growth and sink capacity and biochemical characters were recorded at different stages.

The data on pod ontogeny were subjected to statistical analysis by fitting polynomial function analysis of suitable degree to time interval as independent variate (X) with pod character as dependent variate (Y).

The five genotypes were categorized into following three classes.

1. Short pod development (PDP) and seed growth periods (SGP) with higher pod development (PDR) and seed growth rate (SGR) *viz.* C 152 and VCM 8.
2. Medium pod development (PDP) and seed growth periods (SGP) with constant pod development (PDR) and seed growth rate (SGR) *viz.* Konkan Safed and GC 3.
3. Long pod development (PDP) and seed growth periods (SGP) with slow pod development (PDR) and seed growth rate (SGR) *viz.* Phule Pandhari.

The average duration of cowpea from sowing to maturity was 79 days. However, the minimum maturity period was noticed in VCM 8 (69 days) and maximum of 87 days in Konkan Safed.

The average period of appearance of first flower bud was 42 days and that of setting of first pod was 44 days irrespective of the varieties. The flower bud formation staggered from 33 to 71 days. The first pod maturity occurred within average 63 days. The staggered flowering for a period of 30 to 35 days was a reason for extending the duration than hypothetical expected period of 63 days. The components of maturity were as below;

Total maturity period	=	Days to first flower bud	+	Bud to flower anthesis	+	Duration for flowering to pod set	+	Pod set to Maturity
i. e. 63	=	42	+	1	+	2	+	18

Pod ontogeny

On an average 43 days were required for first flower bud. In next consecutive two days flowering and pod setting occurred. The maximum pod shell weight was achieved within 12 days after flowering. The equatorial diameter of pod was within 15 days after flowering. The elongation of pod was completed 3 days after maximum width. Maximum girth and volume were achieved after 18 days from flowering. Thus whole process of development of pod shell achieved within 18 days from flowering. The deposition of assimilates into pod shell was earliest event, which occurred before complete elongation, widening and final volume of pod. Thus, assimilates are gathered at beginning in the sink and they are utilized for development of pod in entire dimension.

The polynomial fitted for pod wall indicated two prominent types of trends in the changes in dry weight of pods from setting to maturity.

1. Low initial dry weight but high growth rate in next phase e.g. Phule Pandhari, C 152 and Konkan Safed.
2. High initial weight but low rate of pod growth in next phase e.g. VCM 8 and GC 3

Actual and effective pod development period

The actual pod development period of five cowpea genotypes was 18.55 days whereas effective pod development period was 11.45 days. Thus, the effective period was shorter than the actual pod development period by 7.10 days. The difference is referred to as lag period. The genotypes, Phule Pandhari, GC 3 and Konkan

Safed had longest actual, effective pod development period and lag period, respectively. However, C152 had minimum actual and effective pod development and VCM 8 had minimum lag period.

Actual and effective seed growth period

The average actual and effective seed growth period for five cowpea genotypes is approximately 18.55 and 11.40 days, respectively. Thus, there is a difference of 7.15 days in actual and effective seed growth period. This is a lag period. The longest actual seed growth period was noticed in Phule Pandhari (19.50 days). The effective seed growth period was the longest in GC 3 followed by Phule Pandhari. It was minimum in C 152. Lag period is the period during which there is no growth of grain, hence would be desirable to have minimum lag period. VCM 8 had minimum lag period. The genotype, C 152 had least actual and effective growth period and lower lag period maintained higher yields amongst other genotypes.

Seed growth

In general, the pod setting occurs 2 days from flowering and seed setting starts two days from pod setting. The maximum volume of seed is reached within 15 days after flowering, whereas, growth by length and girth is continued upto 18 days after flowering. The maximum dry weight of seed is achieved within 21 days after flowering. Thus, growth of seed by length, breadth, girth and volume is completed within 15 days after flowering and deposition of assimilates is completed in next 6 days. This is in contrast with the development of pod shell. In pod shell the assimilates are deposited in the beginning and they are subsequently utilized for elongation and expansion of pod shell.

The quadratic equation of the form for pod and seed development

As per the polynomials fitted for characters of pod development the genotypes, VCM 8 and GC 3 has extremely negative value of b_0 but had maximum value of b_1 for all the characters which suggested that there was a rapid increase in pod length, breadth and diameter, seed length and breadth, fresh and dry weight of seed, pod shell and pod, volume of seed and pod. The genotypes had coefficient of determination (R^2) values greater for dry matter accumulation than 0.8 between characters of pod development and time interval.

Seed / pod growth rate

The pod and seed growth rate increased progressively with the advancing age of the crop in all genotypes. The genotype C 152 maintained higher seed and pod growth rate followed by Konkan Safed and GC 3 at various stages of growth. The relative growth rate of seeds and pods declined towards maturity. The genotypes under study exhibited independent behaviors for relative growth rate of seeds and pods. VCM 8 and C 152 was initially rather high relative growth rate for seeds and pod.

Biomass partitioning

The per cent dry matter was higher in stem at initial stage of growth and declined steadily towards maturity in all the genotypes, whereas, in leaves it was higher between 40 and 60 DAS than at 20 DAS. After 60 DAS, it decreased towards maturity. The per cent dry matter in leaves was rather higher than roots and stem from 60 DAS and steady towards maturity.

At the time of maturity, dry matter accumulation was diverted to pod development resulted in higher percent dry matter in pods.

At the time of harvest, pods achieved 38.32% percent dry matter was followed by stem (33.60%), leaves (17.42%) and root (10.66%) which is due to the fact that the dry matter accumulation was diverted to pod development and ultimately resulted in higher dry matter accumulation in pods.

Growth parameters

The growth parameters showed relevance with pod ontogeny. During the development of pod shell The AGR was slow. However, during seed filling, seed development and maturation, the magnitude of AGR were high. The RGR values during vegetative growth were high whereas at maturity they become low.

The high values of NAR from 60 DAS indicated that the process of pod development and seed filling is highly supported by high values of photosynthetic rate. The LAR decreased progressively with the advancing age of the crop in midlate and late maturity group genotypes. The genotype, Konkan Safed and GC 3 had higher rate of LAR and NAR at pod development stages.

The high LAI and SLA at the time of pod shell formation, seed filling and pod development supports to higher diversion of photosynthates to reproductive parts. The genotypes, Konkan Safed and Phule Pandhari had higher values for LAD at the time of pod development was promising for biomass production.

The genotypes, VCM 8 and Phule Pandhari were more efficient in respect of AGR, RGR, NAR and LAR, whereas Konkan Safed, C 152 and CG 3 were efficient for LAR, SLA and LAD.

Physiological parameters

The physiological parameters showed relevance with pod ontogeny. The rate of photosynthesis and water use efficiency was higher during pod shell formation, seed filling and seed

development which lowers during seed maturation indicating the mobilization of food material from pod shell towards seed filling and development.

The rate of transpiration and stomatal conductance became higher during vegetative growth and pod shell development and exhibited relevance with pod ontogeny.

Vegetative growth and source

The five genotypes could be morpho-physiologically grouped on the basis of their growth habit as under;

1. Phule Pandhari, C 152 and Konkan Safed come under tall group, profuse branching higher number of leaves and leaf area.
2. GC 3 under midtall, less number of branches, medium for number of leaves and leaf area.
3. VCM 8 under dwarf group, less number of branches, minimum for number of leaves and leaf area.

Generative growth and sink capacity

As per the relative ranking the genotype C 152 was found to be promising for yield and yield contributing characters followed by GC 3, Konkan Safed, Phule Pandhari and VCM 8.

Bio-chemical characters

The biosynthesis of chemical components started during seed filling. It was at slower rate during initial stages. However, it synthesized at faster rate and complete accumulation of reserve food in seed took place within 15 days after flowering.

The five genotypes could be grouped biochemical basis as;

1. Konkan Safed and VCM 8 for protein, carbohydrates and starch content.
2. Phule Pandhari and Konkan Safed for fat and fiber content.

3. C 152 and GC 3 for vitamin content.

Chlorophyll content in pod wall

The chlorophyll content of pod wall showed relevance with pod ontogeny. The chlorophyll content of pod wall was higher at 3 and 6 DAF, thereafter it declined toward seed filling, development and maturation of seed. It indicated that the absorbed energy and translocation of mobilized for seed development.

CONCLUSIONS:

1. The high yielding genotypes, C 152, Phule Pandhari and Konkan Safed had higher values for pod length, pod girth, pod diameter, seed length, seed diameter, fresh and dry weights of pod wall, seeds/pod and pods at various stages of growth. However, the polynomials fitted for pod characters, the genotypes, VCM 8 and GC 3 had lower b_0 and higher b_1 values. It suggested that there was a rapid pod and seed development during the course of growth from the extremely small value at 0 times i.e. at anthesis.

2. The genotypes, VCM 8 and GC 3 had higher growth rate and relative growth rate of seeds and pods at initial stages of growth which becomes ceases with advancing age of the crop. However, the midlate and late maturing genotypes, C 152 and Konkan Safed maintained constant growth rates and relative growth rates of seeds and pods during the course of growth period.

3. The genotype, GC 3 had minimum actual pod and seed development periods (APDP and ASDP) and lag period for pod and seed development, whereas, Phule Pandhari had minimum effective pod and seed development periods (EPDP and ASDP). However, Konkan Safed had maximum APDP, ASDP, EPDP, ESDP and lag period for pod and seed development.

4. The appearance of first flower bud in determinate type of variety (VCM 8) was 33.00 days, which was 41.00 days in

indeterminate type varieties. The average duration of the appearance of first flower bud and flower occurred in 42.10 and 43.05 days, respectively. The average duration for days to setting of first pod was 44.05 days. Thus after anthesis only one more day is required for setting of pods. The average duration of first pod maturity was 62.60 days. The duration from appearance of first pod to first pod maturity was approximately 18 days. The last pod maturity occurred in 74.00 to 87.00 days with an exception of VCM 8 (69.00 days).

5. Konkan Safed had higher dry matter production and its assimilation in component parts of plant at various stages of growth followed by C 152 and Phule Pandhari. The percent allocation of dry matter was higher in pods followed by stem, leaves and root. These genotypes were also promising for higher rates of growth parameters. The genotypes, Konkan Safed and C 152 had higher rate of photosynthesis and transpiration, whereas, GC 3 and C 152 had higher water use efficiency and stomatal conductance.

6. Phule Pandhari and C 152 recorded higher plant height and number of branches per plant, whereas, Konkan Safed recorded higher number of leaves, leaf area per plant and bold seed size. The genotypes, C 152 and Phule Pandhari were found to be promising for yield and yield contributing characters. GC 3 and VCM 8 maintained higher harvest index.

7. The genotypes, GC 3, C 152 and Konkan Safed were promising for protein, carbohydrates, starch, fat fiber, and vitamin content. The higher chlorophyll 'a', 'b' content and total chlorophyll was maintained by VCM 8, Phule Pandhari and GC 3 at various stages of growth.

It can be concluded that the genotypes, C 152, Konkan Safed and Phule Pandhari have higher pod and seed lengths, breadth,

diameter, volume and weights. The actual and effective pod development and seed growth periods and lag periods were higher for Phule Pandhari and Konkan Safed and minimum for C 152 and VCM 8. VCM 8 and GC 3 possessed higher seed and pod growth rates and relative growth of seeds and pods. VCM 8 and GC 3 begin reproductive growth 12-15 days earlier than other genotypes. C 152, Konkan Safed and Phule Pandhari maintained higher dry matter production and its assimilation in component parts of plants, growth functions, physiological characteristics, vegetative growth and source characters and generative growth and sink capacity. Therefore, the genotypes, VCM 8 and GC 3 were promising for boosting up early characteristics in breeding programme, whereas, C 152, Konkan Safed and Phule Pandhari were promising the development of genotypes with higher biomass.

The present investigations have clearly brought out the importance of reproductive growth approaches in locating the causes for yield differences in cowpea. In this context, the model appeared for seed and pod development based on the periodical data of pod and seed growth generated from five divergent genotypes of cowpea. It can be used as heuristic model for understanding the phenomenon and planning of research programme. Thus, pod and seed growth in terms of length, breadth, width and pod shell growth in terms of fresh and dry weight and growth rates appeared to be highly predictable and the genetic variations can be predictably studied in cowpea (Table 78).

Table 78. Promising genotypes of cowpea for respective characters

Name of the character		Promising genotypes		Name of the character		Promising genotypes	
1. Fresh weight and dry weights of flower.		Konkan Safed and GC 3		11. Fresh weight of pods		C 152 and Konkan Safed	
2. Pod length		C 152, GC 3 and Konkan Safed		12. Dry weight of pod wall		C 152 and Konkan Safed	
3. Pod girth		C 152, Phule Pandhari and Konkan Safed		13. Dry weight of seeds/ pod		C 152 and Konkan Safed	
4. Pod diameter		C 152, Phule Pandhari and Konkan Safed		14. Dry weight of pods		C 152 and Konkan Safed	
5. Seed length		Konkan Safed, C 152 and Phule Pandhari		15. Seed growth rate		VCM 8 and CG 3	
6. Seed girth		Phule Pandhari and C 152		16. Pod growth rate		VCM 8 and CG 3	
7. Pod volume		Konkan Safed and C 152		17. Relative growth rate of seed		VCM 8 and CG 3	
8. Seed volume		Konkan Safed and C 152		18. Relative growth rate of pod		VCM 8 and CG 3	
9. Fresh weight of pod wall		C 152 and Konkan Safed		19. APDP and EPDP		GC 3 and Phule Pandhari	
10. Fresh weight of seeds/ pod		C 152 and Konkan Safed		20. ASDP and ESDP		GC 3 and Phule Pandhari	
II. Characters of reproductive growth							
Days to appearance of 1 st flower bud and last flower bud, 1 st flower and last flower, 1 st pod and last pod, 50% flowering, 50% podding, 1 st pod maturity and last pod maturity				VCM 8 and CG 3			
III. Growth analysis							
Dry matter production and it's assimilation in component parts of plant			Growth parameters			Physiological parameters	
Roots	Konkan Safed and Phule Pandhari		AGR	VCM 8 and Phule Pandhari		P _n	C 152 and Konkan Safed
Stem	Konkan Safed, C 152 and Phule Pandhari		RGR	VCM 8 and Phule Pandhari		T _n	Konkan Safed and Phule Pandhari
Leaves	Konkan Safed, Phule Pandhari and C 152		NAR	VCM 8 and Konkan Safed		WUE	C 152 and Konkan Safed
Pods	C 152 and Phule Pandhari		LAI	Konkan Safed and Phule Pandhari		SC	C 152 and GC 3
Total	Konkan Safed and GC 3		LAR	VCM 8 and GC 3			
			SLA	Phule Pandhari and C 152			
			LAD	Konkan Safed and Phule Pandhari			
IV Morphological characters							
Vegetative growth and source			Generative Growth and Sink Capacity.				
Plant height	Phule Pandhari, C 152 and Konkan Safed		Number of pods/ plant	C 152 and GC 3	Seed Yield/ plot	C 152 and Phule Pandhari	
Number of branches/ plant	Phule Pandhari and C 152		Seeds/ pod	C 152 and Phule Pandhari	Seed yield (kg/ ha)	C 152 and Phule Pandhari	
Number of leaves/ plant	Konkan Safed and Phule Pandhari		Seeds/ plant	C 152 and GC 3	Fodder yield (kg/plot)	C 152 and Phule Pandhari	
Leaf area/ plant	Konkan Safed and Phule Pandhari		Seed yield/ plant	C 152 and GC 3	Biological yield (Kg/plot)	C 152 and Phule Pandhari	
			100 seed weight	Konkan Safed and GC 3	Harvest index	GC 3 and VCM 8	
V. Proximate composition							
Protein	GC 3, Konkan Safed	Fat	Phule Pandhari, Konkan Safed		Vitamin A	Konkan Safed, C 152	
Reducing sugars	GC 3, C 152	Fiber	C 152, GC 3		Chl. a (pod wall)	GC 3, Phule Pandhari	
Carbohydrate	C 152, Konkan Safed	Niacin	C 152, Phule Pandhari		Chl. b (pod wall)	GC 3, C 152	
Starch	GC 3, VCM 8	Thymine	GC 3, C 152, VCM 8		Total chlorophyll	GC 3, C 152	

7. LITERATURE CITED

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- a) Life member of Journal of Maharashtra Agricultural Universities, College of Agriculture, Pune-411 005.
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SEVICE DETAILS:

Post/ designation	Employer	Place of work	Period	Nature of duties
Junior Research Assistant	Registrar, MPKV, Rahuri.	AICPMIP, College of Agriculture, Pune- 411 005	26.05.1988 to 01.08.1994	Research
Junior Research Assistant	Registrar, MPKV, Rahuri.	Agricultural Research Station, Vadgaon (Maval), Dist.: Pune	02.08.1994 to 04.01.1999	Research and Extension
Senior Research Assistant	Registrar, MPKV, Rahuri.	Pulses Improve-ment Project, MPKV, Rahuri	05.01.1999 to 31.08.2010	Research and Extension
Senior Research Assistant	Registrar, MPKV, Rahuri.	Department of Botany, MPKV, Rahuri	01.09.2010 to till today	Research

ANY OTHER RELEVANT INFORMATION:

Passed 'National Eligibility Test (NET)' in Plant Physiology (Agricultural and Horticultural crops) conducted by ICAR, New Delhi in the year 2004.

PUBLICATIONS:

a) Scientific (Internationally abstracted):	Full papers:	24
	Short notes:	8
	News letters:	11
b) Technical (symposia/ conference):	Full papers:	2
	Abstracts:	38
c) Extension (Popular articles):		11
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Examination passed	Year	Class	CGPA	% of marks	University/ Board
S. S. C.	1979	I st	--	63.47	M. S. Board of Secondary and Higher Secondary Education, Pune.
H. S. C.	1981	II nd	--	55.17	
B. Sc. (Agri.)	1984	I st	3.06/ 4.00	68.85	MPKV, Rahuri, Dist.: Ahmednagar.
M. Sc. (Agri.)	1987	I/ D	3.51/ 4.00	74.32	KKV, Dapoli, Dist.: Ratnagiri

b) Dissertation for M. Sc. (Agri.) degree programme:

1. "Physiological Analysis of Growth and Yield Variation in Horsegram (*Macrotyloma uniflorum* (L) Verdc)" submitted to Konkan Krishi Vidyapeeth, Dapoli, Dist.: Ratnagiri in the year 1987 for M. Sc. (Agri.) degree.

c) Contributed for the development of varieties.

1. Rice variety: Phule Maval (VDN-12237):
2. *Kabuli* chickpea variety: Virat (Phule G-95418).
3. *Kabuli* chickpea variety: Vihar (Phule G-95311).
4. *Desi* chickpea variety: Digvijay (Phule G 9425-5)
5. *Desi* chickpea variety: Rajas (Phule G 9425-9)
6. *Kabuli* chickpea variety: Kripa (Phule G 9915)

APPENDIX-I

Growth rates for pod and seed growth characters

Genotypes	Days after flowering						
	3-6	6-9	9-12	12-15	15-18	18-21	21-24
Pod length (cm/day)							
VCM 8	1.60	1.21	0.21	-0.27	0.00	-0.01	0.00
Konkan Safed	1.17	1.23	0.66	0.14	-0.14	-0.19	0.00
Phule Pandhari	1.52	1.26	0.50	0.07	-0.12	-0.01	0.00
C 152	0.94	2.46	0.23	0.03	-0.35	-0.04	0.00
GC 3	1.96	1.00	0.49	0.01	-0.10	-0.14	0.00
Pod girth (mm/day)							
VCM 8	1.50	2.63	0.37	-0.32	-0.30	0.00	-0.01
Konkan Safed	1.17	2.31	0.99	0.38	-0.10	-0.59	0.00
Phule Pandhari	1.48	2.80	0.30	0.20	-0.14	-0.02	0.00
C 152	1.31	2.87	0.90	0.07	-0.15	-0.06	0.00
GC 3	2.75	1.75	0.48	0.09	-0.60	-0.13	0.00
Pod diameter (mm/day)							
VCM 8	0.48	0.84	0.12	-0.10	-0.09	0.00	0.00
Konkan Safed	0.37	0.74	0.31	0.12	-0.03	-0.19	0.00
Phule Pandhari	0.47	0.89	0.10	0.06	-0.04	0.00	0.00
C 152	0.42	0.91	0.29	0.02	-0.05	-0.02	0.00
GC 3	0.88	0.55	0.15	0.03	-0.19	-0.04	0.00
Seed length (mm/day)							
VCM 8	0.74	1.08	0.70	-0.09	-0.82	-0.01	0.00
Konkan Safed	0.75	1.11	0.17	0.58	-0.03	-0.43	0.00
Phule Pandhari	0.77	1.13	0.49	0.17	-0.61	-0.04	0.00
C 152	0.70	1.02	0.70	0.31	-0.45	-0.18	0.00
GC 3	0.76	1.11	0.53	0.25	-0.59	-0.15	0.00

APPENDIX-I. Contd...

Genotypes	Days after flowering						
	3-6	6-9	9-12	12-15	15-18	18-21	21-24
Seed diameter (mm/day)							
VCM 8	0.34	0.61	0.39	-0.07	-0.30	-0.02	0.00
Konkan Safed	0.37	0.65	0.17	0.28	0.00	-0.26	0.00
Phule Pandhari	0.38	0.67	0.41	0.03	-0.19	-0.05	0.00
C 152	0.35	0.61	0.57	-0.01	-0.17	-0.09	0.00
GC 3	0.39	0.69	0.24	0.06	-0.12	-0.08	0.00
Pod volume (ml/day)							
VCM 8	0.07	0.72	0.19	-0.30	-0.08	-0.02	-0.01
Konkan Safed	0.09	0.57	0.52	0.14	-0.02	-0.27	0.00
Phule Pandhari	0.13	0.52	0.41	0.18	-0.28	-0.12	0.00
C 152	0.09	0.76	0.65	-0.13	-0.26	-0.14	0.00
GC 3	0.17	0.59	0.22	0.29	-0.46	-0.12	0.00
Seed volume (ml/day)							
VCM 8	0.008	0.028	0.024	-0.013	-0.008	-0.001	0.000
Konkan Safed	0.008	0.018	0.040	-0.002	0.002	-0.007	0.000
Phule Pandhari	0.008	0.018	0.031	0.003	-0.020	-0.002	0.000
C 152	0.009	0.019	0.039	-0.003	-0.017	-0.001	0.000
GC 3	0.011	0.027	0.018	0.005	-0.014	-0.008	0.000
Fresh wt of pod wall (g/day)							
VCM 8	0.13	0.41	-0.15	-0.16	-0.12	-0.02	-0.01
Konkan Safed	0.10	0.31	0.07	-0.18	-0.03	-0.16	-0.04
Phule Pandhari	0.09	0.28	0.10	-0.21	-0.19	-0.01	-0.01
C 152	0.07	0.37	-0.01	-0.16	-0.14	-0.01	0.00
GC 3	0.15	0.26	0.20	-0.18	-0.32	-0.03	-0.01

APPENDIX-I. Contd...

Genotypes	Days after flowering						
	3-6	6-9	9-12	12-15	15-18	18-21	21-24
Fresh weight of pods (g/day)							
VCM 8	0.16	0.42	0.28	-0.24	-0.19	-0.05	-0.05
Konkan Safed	0.14	0.51	0.43	0.02	-0.01	-0.46	-0.12
Phule Pandhari	0.12	0.47	0.25	0.13	-0.49	-0.04	-0.02
C 152	0.10	0.49	0.67	0.00	-0.55	-0.07	-0.02
GC 3	0.18	0.52	0.44	0.05	-0.62	-0.04	-0.05
Fresh weight of seeds/pod (g/day)							
VCM 8	0.037	0.173	0.270	-0.082	-0.114	0.000	-0.030
Konkan Safed	0.038	0.198	0.365	0.206	0.001	-0.252	-0.112
Phule Pandhari	0.032	0.189	0.271	0.212	-0.302	-0.029	-0.011
C 152	0.031	0.205	0.597	0.110	-0.356	-0.062	-0.023
GC 3	0.041	0.255	0.240	0.227	-0.306	-0.011	-0.039
Dry weight of pod wall (g/day)							
VCM 8	0.015	0.044	0.003	0.005	0.004	0.009	0.001
Konkan Safed	0.015	0.037	0.038	0.016	0.003	0.012	0.001
Phule Pandhari	0.019	0.034	0.030	0.012	0.004	0.003	0.003
C 152	0.012	0.044	0.067	0.022	0.022	0.002	0.003
GC 3	0.025	0.030	0.009	0.018	0.020	0.008	0.003
Dry weight of seeds/pod (g/day)							
VCM 8	0.004	0.047	0.117	0.038	0.025	0.023	0.001
Konkan Safed	0.005	0.028	0.190	0.158	0.051	0.013	0.001
Phule Pandhari	0.004	0.028	0.122	0.183	0.011	0.008	0.002
C 152	0.004	0.031	0.257	0.154	0.033	0.006	0.018
GC 3	0.005	0.042	0.078	0.150	0.112	0.018	0.002

APPENDIX-I. Contd...

Genotypes	Days after flowering						
	3-6	6-9	9-12	12-15	15-18	18-21	21-24
Dry weight of pods (g/day)							
VCM 8	0.019	0.091	0.120	0.052	0.019	0.033	0.002
Konkan Safed	0.019	0.066	0.229	0.173	0.054	0.025	0.002
Phule Pandhari	0.016	0.068	0.152	0.195	0.015	0.010	0.006
C 152	0.016	0.075	0.324	0.176	0.055	0.016	0.013
GC 3	0.029	0.072	0.087	0.168	0.132	0.022	0.009