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BIOCHEMICAL CHANGES DURING FRUIT MATURATION IN COCONUT*

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ABSTRACT

Literature relevant to the biochemical changes occurring in the endosperm of the developing fruit, from the time of fertilization to maturity, is reviewed. The biosynthesis and utilisation of the major fruit components at various growth stages and the interrelationships among them are discussed. It is pointed out that the discovery of the involvement of α D- galactosidase in the formation of normal endosperm and in the control of germination is of major importance and should lead to more work on the mutant 'Makapuno' for a better understanding of the control mechanisms. Comparative studies of several coconut genotypes during fruit development are recommended in order to enhance their utility in the food industry and in the manufacture of other products. Some of the major areas for future work are listed.

INTRODUCTION

The fruit of the coconut, botanically known as a fibrous drupe consists of the endospermous kernel with the embryo embedded in it, and externally protected by the fruit coat known as the pericarp. The pericarp consists of three distinct and well defined regions, namely, epicarp, mesocarp and the endocarp. Within the kernel is a cavity which in the unripe fruit is completely filled with the liquid endosperm, popularly known as "coconut water".

The kernel is economically the most important part of the fruit. In view of its prime importance, a great deal of fundamental work on the biochemistry of nut maturation has been carried out. In this paper the current status of knowledge with reference to the developmental changes during fruit ripening is presented.

Ontogeny of fruit

The fruit development in coconut from the time of initiation of inflorescence primordium to full maturity of the nut could be divided into two major phases, namely pre-fertilization phase taking about 32 months and the post fertilization phase continuing for another 12 months, mainly by cell enlargement which is associated with the accumulation of food reserves (Patel, 1938).

Pattern of fruit growth:

The growth of the fruit begins, immediately following fertilization, with a rapid development of the pericarp at the basal region which remains soft and white until the fruit is nearly mature. The endocarp is already differentiated as a soft, creamy white structure long before the time of fertilization. During the development of fruit to maturity the embryo sac increases in size, leaving a large vacuole at the centre (Winton, 1901; Juliano, 1926). The coconut water is formed in small quantities in the third month of development of the nut and reaches maximum in the eighth month and declines thereafter as the nut ripens. The endosperm

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*Contribution No. 780, Central Plantation Crops Research Institute, Kasaragod of coconut developes as a coenocytic liquid containing many free nuclei and some cells (Cutter, Wilson and Freeman, 1955; Bhatnagar and Johri, 1972). The cells coalesce towards the periphery of the embryo sac. Additional cells are formed when free nuclei adhere resulting in the formation of cellular endosperm. In the mature coconut, the liquid which is of cytoplasmic origin (Kumar et al., 1985) does not contain free nuclei or free cells (Cutter, Wilson and Freeman, 1955). The shell begins to form during the fourth month of nut development and continues to grow upto the twelfth month. The kernel is the last component to begin formation in the seventh month and its growth continues upto the eleventh month when the maximum value of dry weight is reached (Fig. 1). The growth of the kernel is of a 'blitz' nature for the first two or three months during which time it gathers most of its raw material. The percentage development of the fruit parts during ripening are shown in Fig. 2. The reddish testa which assumes a brownish tint when mature is laid down before the formation of the kernel. Its growth is proportionately greater than that of kernel during the early stages (Kartha and Narayanan, 1956).

Most of the information currently available with regard to fruit development in coconut have centred round the changes occurring in the endosperm (both kernel and nut water) as they play an important part in germination and seedling development. Hence, in this review, the changes in the shell and husk during fruit ontogeny have not been considered.

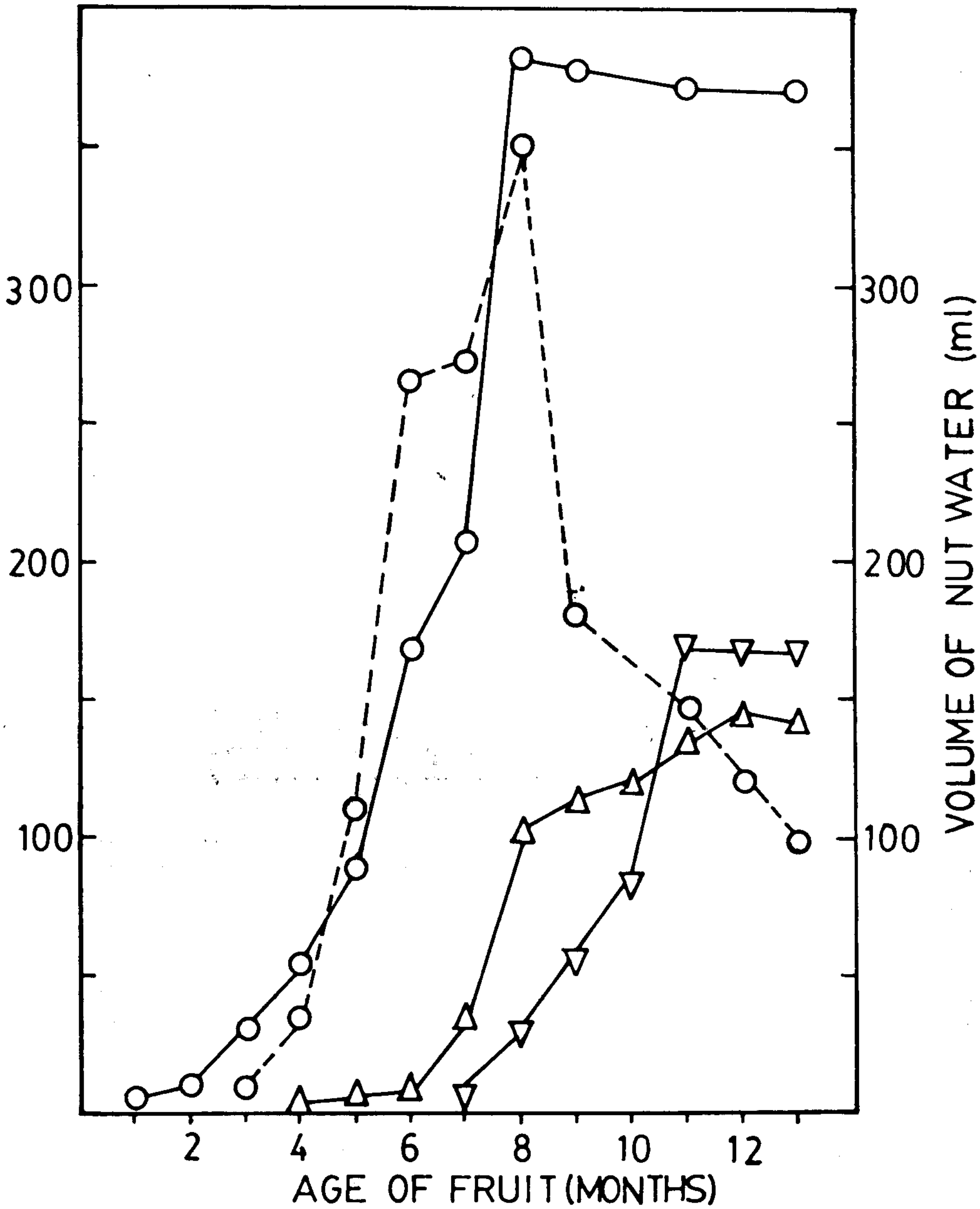
Biochemistry of the developing fruit

The liquid endosperm plays a vital role in fruit development by acting as a reservoir of precursors for the synthesis of fruit constituents. The major chemical constituents of the liquid endosperm are sugars and minerals while fat and nitrogenous substances form a minor fraction (Kamala Devi and Velayudham, 1978).

Changes in carbohydrates:

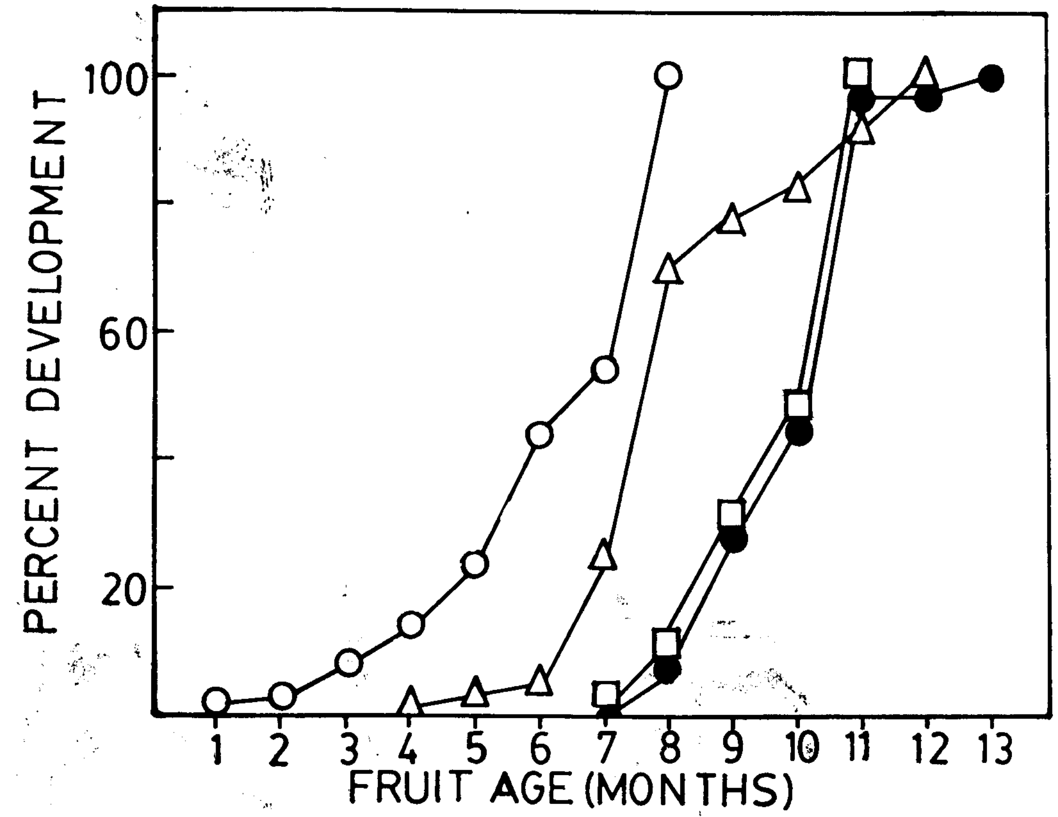
Van slyke (1891) was the first to report that reducing sugars formed the major part of unripe nuts. Subsequent work by several workers (Child and Nathanael, 1950; Nathanael, 1952) confirmed that the sugars present in the water of the immature fruit, in which the cavity has just formed, are almost entirely reducing sugars increasing in concentration to a maximum of about 5% upto the seven-month old stage when the fruit has attained full size but is still unripe (Child and Nathanael, 1950) (Fig. 3). During this period of fruit development, the sugar in the sap of the inflorescence axis entering the fruit undergoes complete conversion from sucrose to glucose and fructose by the action of invertase present in the stalk (Balasubramaniam, 1983; Balasubramaniam and Alles, 1989). With the appearance of solid endosperm (kernel) at about the seventh month of growth, non-reducing sugars appear and thereafter increase in concentration both in the kernel and nut water (Balasubramaniam, 1983) while the levels of both reducing sugars and total sugars decrease. Simultaneously, the polysaccharides in the kernel increase following a sigmoid pattern. The initial lag phase of polysaccharide synthesis continues until the establishment of the jelly-like endosperm on the entire surface area of the nucellus. This is followed by a logarithmic phase in which the jelly-like endosperm gradually thickens and turns hard. The stationary phase is characterized by the formation of a hard solid endosperm in which almost all the cell wall polysaccharides are laid down (Balasubramanian, 1983). The fat content of the kernel also shows an increase during the same period (Pillai, Sukumaran and

Fig. 1. Growth of fruit parts at various stages of development (O—O husk, △—△ shell; ▽—▽ kernel and O— —O nut water) (Ref: Pillai, Sukumaran and Pandalai, 1959)



Pandalai, 1959; Jayalekshmy et al., 1988). These results appear to indicate that the glucose of the liquid endosperm is converted to sucrose and to the polysaccharides of the kernel, besides being utilized as a precursor for synthesis. The total carbohydrate content

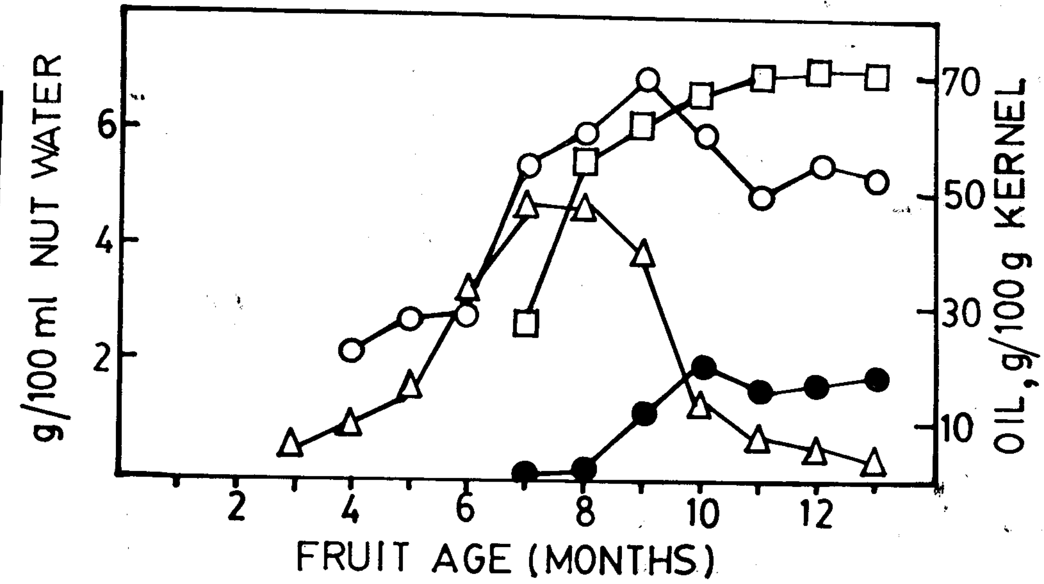
Fig. 2. Percentage development of husk (O—O) shell (△—△), kernel (□—□) and oil (●—●) during fruit growth (Based on the maximum amount developed) (Ref: Pillai, Sukumaran and Pandalai, 1959)



of the kernel increases from 31.9% in the 6th month to 44.9% at maturity during which time free sugars increase from 11.3% to 23.6% (Sierra and Balleza, 1972). Sucrose contributes to the synthesis of nearly 20% of the lipids stored in the endosperm and a large number of polysaccharides including cellulose stored in its pericarp (Van die, 1974).

Composition of carbohydrates in nut water: Caray (1924) isolated three sugars namely, glucose, fructose and sucrose from the liquid endosperm. Traces of an unidentified trisaccharide co-eluting with raffinose (galactose-glucose-fructose) and an unidentified tetrasaccharide co-eluting with stachiose (Glucose - galactose - glucose - fructose) have been isolated from the nut water of dwarf and tall varieties respectively (Enonuya, 1988). White et al. (1989) have isolated from the liquid endosperm of mature coconuts, a polysaccharide presumably an arabinogalactan, with a molecular weight exceeding 500,000 daltons and composed predominantly of galactose and arabinose with minor amounts of mannose and glucose. Two smaller polysaccharides containing significant amounts of xylose or mannose and lesser amounts of arabinose and another polysaccharide composed exclusively of uronic acid residues have also been reported.

Fig. 3. Composition of nut water at different stages of fruit development (O—O) soluble salts; △—△ reducing sugars; ●—● non reducing sugars and □—□, oil) (Ref: Pillai, Sukumaran and Pandalai, 1959)



Carbohydrate composition of kernel: Galactomannans and galactoglucomannans were considered to be the major polysaccharide of the mature coconut kernel (Rao, Chowdhury, and Bagchi, 1961; Mukherjee and Rao, 1962; Kooiman, 1971; Balasubramaniam, 1976) and Coprameal (Maki, et al. 1981) respectively. However, studies by Saitagaroon, Kawakishi and Naniki (1983) indicate that mannan is the major polysaccharide of copra meal accounting for nearly 61% of the deproteinized holocellulose. The copra meal contains substantial amounts of cellulose, minor amounts of arabinoxylogalactan, galactomannan and traces of arabinomannogalactan and galactoglucomannan. The polysaccharides present in the copra meal and their monosaccharide composition are shown in Table I.

The primary cell walls of the immature kernel cells are formed of cellulose and the matrix polysaccharide, galactomannans (Balasubramaniam 1976). During fruit maturation, the 17% NaOH (extractable) galactomannans (galactose to mannose 1:7) increase, possibly by the hydrolysis of the precursor galactomannan extractable with 4% NaOH (galactose to mannose 1:2). Some of the galactoses in galactomannans have been shown to be d-linked (Balasubramaniam, Dey and Pridham, 1974). During the transition of the endosperm from the hydrated gelatinous phase to the dehydrated solid mature state, most of the galactose groups are removed from the cell wall galactomannans (Kooiman, 1971). This process is catalysed by the enzyme α D-galactosidase present in the endosperm (Mujer, Ramirez and Mendoza, 1984 a, b). The mannans are absent in the kernel of 5-6 month old fruits while the mature nut consists chiefly of mannans containing at most a few percent of galactose residues (Mujer, Ramirez and Mendoza, 1983a).

Changes in amino acids:

The developing fruit contains a variety of nitrogenous substances, of which free

Table I. *Polysaccharides of copra meal*

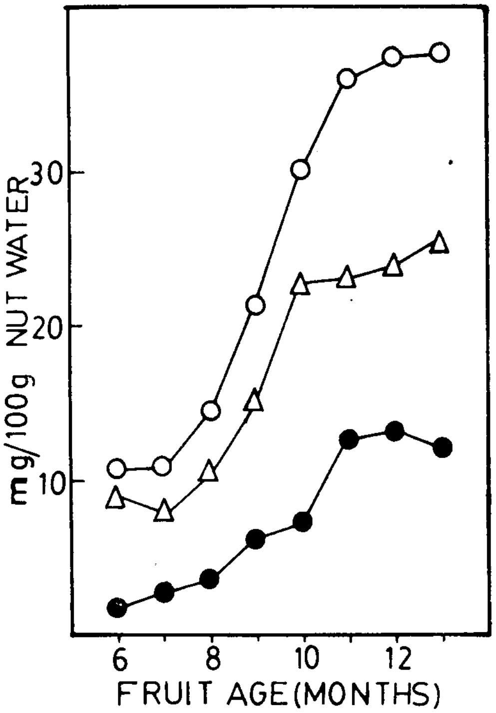
Polysaccharide	Fraction	Mol wt.	Monosaccharide composition	Molar ratio
Mannans	A		man:gal	
	B3	4 5×10^8	man:gal	48:1
	B5 (E)	1 2×10^8	man:gal	31:1
Galactomannans	B5 (D)	1 2×10^8	man:gal	9:1
	B5 (F)	1 2×10^8	man:gal	12:1
Arabinoxylogalactans	B1	1×10^8	Xyl:ara:gal (and traces of man & glu)	1:4:5
	B2	1×10^5	Xyl:ara:gal („)	1:4:5
	B4	1 2×10^8	Xyl:ara:gal:man	1:3:3:1
	B5 (A)	„	Xyl:ara:gal	1:3:3
	B5 (B)	„	Xyl:ara:gal	1:3:3
Arabinomannogalactans	HWE 1	1×10^5	Xyl:ara:gal:man	1:4:5:7
	HWE4	1×10^8	ara:man:gal	5:2:9
	HWE2	1×10^5	glu:gal:man	3:10:18
Galactoglucomannans	HWE3	2×10^8	glu:gal:man	1:1:5
Mannan + Cellulose	Residue		man:glu	—

(Source: Saitagaroon, Kawakishi and Naniki, 1983)

amino acids constitute a major part (Baptist, 1956; Tulecke et al., 1961). During fruit ripening, the total nitrogen and non-protein nitrogen (NPN) show a progressive increase although their levels decrease marginally on whole nut basis (Fig. 4). The NPN content remains more than 60% at any stage of maturity. (Jayalekshmy et al., 1988). Pillai (1964) showed that in the ripening nut the free amino acid (FAA) content in coconut water increases from 4 mg/100 ml to 16 mg/100 ml whereas its concentration in the kernel decreases. The concentration of bound amino acids however, do not show any marked change (Baptist, 1956; Pillai, 1964).

Composition of amino acids: Variations in the amino acid composition of the developing endosperm have been reported by several workers. (Baptist, 1956) found that γ- amino butyric acid makes its appearance in the water with the formation of the kernel, about 5–6 months after the fruit set and subsequently increases with maturity. α-alanine and β-aminobutyric acid are present in large quantities in the endosperm of the immature nut (Gunawardena, 1973). The occurrence of pipecolic acid in the soluble nitrogenous fractions of tendernut kernel has been reported (Pillai, 1964). Proline content is highest in the immature nut and decreases with maturity leaving only a trace in the water of the mature nut (Baptist,1956). In the immature nut water, about 70% of the free amino acids are made up of glutamine, arginine, asparagine, alanine and aspartic acid while alanine, γ-aminobutyric acid and glutamic acid constitute about 75% of the

Fig. 4. Changes in the protein N (●-●), non-protein N (△-△) and total N (O-O) of coconut water during fruit ripening. (Ref : Jayalekshmy, Arumugham, Narayanan and Mathew, 1988)



free amino acids of mature nut water (Anonymous, 1961). Aspartic acid, glutamic acid, serine, alanine, valine, leucine and isoleucine are found at all stages of fruit development. With increasing age of the fruit, aspartic acid and glutamic acid increase slightly while alanine increases markedly. Other amino acids do not show much change (Baptist, 1956). There is some disagreement with regard to the presence of methionine and aromatic amino acids (Baptist, 1956). However, the amino acid analysis of protein fractions of coconut kernel show the presence of all these amino acids (methionine, tyrosine, tryptophan and phenylalanine) at a fairly high level (Hagenmeir, Cater and Mattil, 1972).

Changes in proteins:

The protein content of nut water increases from 0.13% to 0.29% (Subrahmanyan and Swaminathan, 1959) while it decreases in the kernel from 8.3% at the 5th month to 6.2% at maturity (Sierra and Balleza, 1972). The coconut proteins have been classified according to their solubility behaviour (Butterworth and Fox, 1963; Strength, 1970; Samson, Cater and Mattil, 1971). Amino acid analysis (Peters, 1960; Rajasekharan, 1964; Strength, 1970; Samson et al., 1971) and heat denaturation (Butterworth and Fox, 1963; Samson, 1971). About 84% of the coconut proteins are of high molecular weight (150,000 daltons) and the rest belong to low molecular weight (24,000 daltons) class. (Hagenmeier et al., 1972) (Table II). Osborne classification studies indicate that 90% of the proteins could be classified as albumins and globulins (Samson, Cater amd Mattil, 1971). Wallace and Dieckert (1976) have isolated two molecular weight classes of polypeptides from coconut storage globulins and determined their amino acid composition which agreed reasonably well with the amino acid composition of the starting material with the exception of cystine. The coconut protein resembles the FAO reference protein pattern, the major deficiencies being methionine and threonine (Srinivasan, Indira and Chandrasekhar, 1964).

Enzymes:

The endosperm, being a site of active metabolism, contains a large number of enzymes (Table III).

Wilson and Cutter (1952) showed that the onset of cellular differentiation in the developing coconut coincides with a rapid rise in acid phosphatase activity. The sites of high phosphatase activity show an interesting correlation with those tissues in

Table II. *Amino acid composition of protein fractions* (*g amino acid*/16 *g N*)

Amino acid	Large mol. wt. fraction (150,000 daltons)	Small mol. wt. fraction (24,000 daltons)	95% confidence interval
Lysine	3.44	5.00	0.04
Histidine	2.20	1.05	0.13
Arginine	14.70	22.03	0.74
Tryptophan	0.89	1.02	0.10
Aspartic acid	9.47	2.60	00.21
Threonine	3.29	1.13	0.11
Serine	4.89	1.28	0.09
Glutamic acid	17.94	35.51	0.47
Proline	3.60	2.17	0.33
Glycine	4.41	3.13	0.13
Alanine	4.30	0.59	0.15
Cystine	0.98	3.45	0.21
Cysteine	0.16	0.00	0.03
Valine	6.06	0.80	0.24
Methionine	2.84	0.37	0.16
Isoleucine	4.12	0.28	0.33
Leucine	8.15	1.94	0.72
Tyrosine	2.87	2.61	0.13
Phenylalanine	5.10	0.66	0.18
Total	99.41	85.63	2.32

(Source: Hagenmeier, Cater and Mattil, 1972)

which high endogenous rates of oxygen consumption have been demonstrated (Cutter, Wilson and Dube, 1952). Acid phosphatase activity in the kernel reaches a minimum when the maturation is complete and remains so even during germination. The activities of pyrophosphatase, 3'– nucleotidase, ribonuclease and deoxyribonuclease also remain similar in the kernel of mature and germinating coconuts indicating that mature kernel acts only as a storage tissue. The inability of the mature kernel to utilize oxygen shows that it is incapable of protein synthesis (Cutter et al., 1952). On the contrary, the demonstration and isolation of RNA polymerases (CI and CII) (Mondal, Mandal and Biswas, 1972) and a factor that stimulates RNA polymerase from coconut nuclei (Mondal, Mandal and Biswas, 1970b) of immature coconuts have given evidence for the existence of transcriptional process in them.

Table III. *Enzymes present in endosperms*

Enzymes	Source tissue	Reference
Acid phosphatase	Kernel and embryo of 8–9 month old nut	Sadasivan (1951)
	Nut water Nucellus and Endosperm of 3–12 month old nuts	Wilson and Cutter (1952) Wilson and Cutter (1955)
Decarboxylases	Immature kernel	Baptist and Perera (1965)
Aspartate amino-transferase	Immature kernel	Baptist (1967)
RNA polymerase	Kernel of 4–5 month-old nuts	Mondal, Mandal and Biswas, (1972)
Pyrophosphatase 3' – nucleotidase, Ribonuclease and Deoxyribonuclease	Mature fruit kernel	Balasubramaniam Atukorala, Wijesundera, Hoover and De Silva (1973)
Glycerol dehydrogenase, Amylase Lipase, Phospholipase C.	Mature fruit kernel and cuticle	Krishnamurthy and Chandrasekhara (1979)
Carbonic anhydrase	1–2 month old fruit	Padmaja, Sumathykutty Amma, Chacko Mathew, Ray and Dwivedi (1980)
Mannan synthetase GDP Mannose pyrophosphorylase	Mature fruit kernel	Balasubramaniam (1983)
Peroxidase	7–12 month old normal and makapuno nuts	Mujer and Ramirez (1980) Mujer, Mendoza and Ramirez (1983b)
α D–Galactosidase	6–12 month old fruits	Mujer, Ramirez and Mendoza (1984)
Tryptophan aminotransferase	6–12 month old fruit kernel	Mujer, Ramirez and Mendoza (1984)
CAMP dependent Protein Kinase	Nut water	Janistyn (1989)
Invertase	6–7 month old fruit stalk and mesocarp	Balasubramaniam and Alles (1989) •
Esterase	Mature fruit kernel	Manjula (1990)

Regulation of enzyme activities in the developing nut : The activities of enzymes related to lipid accumulation in the coconut during various stages of development are regulated in such a way as to facilitate the accumulation of oil in the mature fruits. The absence of lipase and esterase activities in the pH 6.3 fraction of the mature fruit (the natural pH of the fruit) helps in the accumulation of oil. The biosynthesis of lipids ceases in the mature fruit due to the high activities of pyrophosphatase and phospholipase C which hydrolyze any high energy phosphate formed from the metabolism of carbohydrates involving amylase. The energy so derived is utilized to meet the energy demands and regulation within the cell (Balasubramaniam and Sihotang, 1979).

Another biochemical process that has been investigated in detail is the degradation of galactomannans in the kernel during fruit maturation. The role of galactomannans have been implicated in the development of the cell wall of coconut and other palm seeds (Kooiman, 1971). In the normal nut, galacto mannans are degraded to mannans during ripening by the hydrolysis of α D–galactosyl groups involving α–galactosidase enzyme (Mathew and Balasubramaniam, 1987). The pattern of α-D galactosidase activity is inversely correlated with the amount of galactomannans obtained at similar developmental stages from the normal endosperm (Mujer, Ramirez and Mendoza 1983 a). However, in the mutant Makapuno nut, there is a deficiency of α–galactosidase, caused either by a continuous repression of enzyme synthesis or the absence of specific effectors (Mujer, Ramirez and Mendoza, 1984). The deficiency of α D–galactosidase activity in Makapuno coincides with a significantly higher level of galactomannans (Mujer et al., 1983 a) resulting in loss of intercellular adhesion, highly elongated cells and amitosis in them. Hence, it is possible that α–galactosidase plays a major role in the formation of the normal endosperm. Incidentally, the failure of Makapuno nuts to germinate under natural environmental conditions could be related to the deficiency of α–D–galactosidase in them (Mujer et al., 1984).

Changes in lipids

Fat synthesis starts at the seventh month, when the kernel begins to form and increases upto the 12th month (Kartha and Narayanan, 1956) (Fig. 2). The fat content of the nut water shows a gradual increase upto the 10th month and rises gradually thereafter (Pillai et al., 1959). (Fig. 3) reaching a maximum in the 12th month. At the same time, the fat content of the kernel also increases and the oil content per nut is at its maximum in the 12 month-old nut (Menon and Pandalai, 1960).

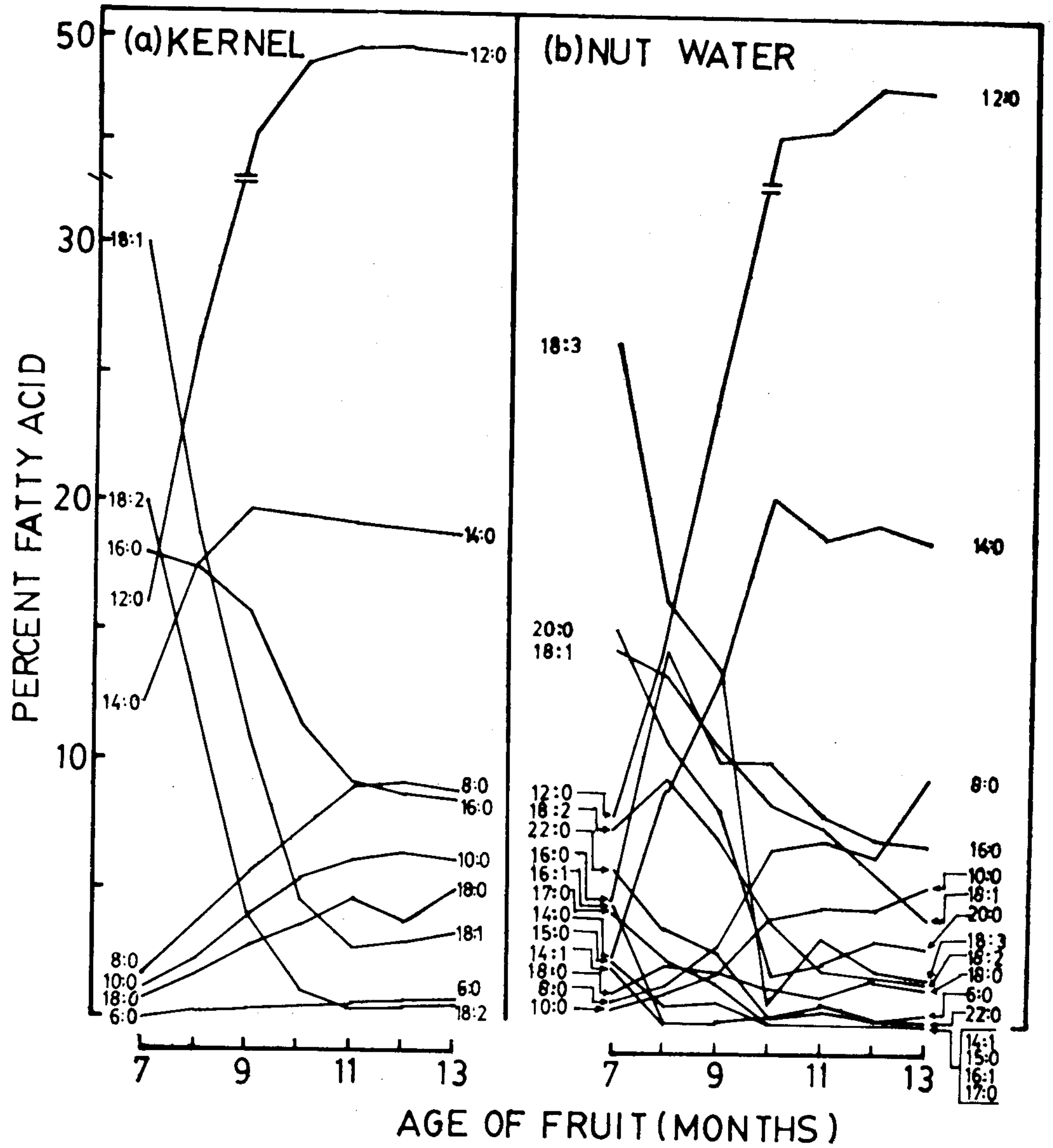
Biosynthesis of fats:

Kartha and co-workers in their pioneering studies showed that the fat depots of the developing nut possess the capacity to selectively synthesize the chainlength-regulating enzyme systems for any chainlength at any time without reference to the nature and proportions of the other systems present. (Sethi and Kartha, 1956). Thus, the different chainlength elongating enzymes in the fat depots are not formed as a single composite unit but as a collection of different independent units (Kartha, Sethi and Narayanan, 1959). A mechanism of 'quantum' synthesis of triglycerides for the biosynthesis of fats in the maturing fruit has been proposed based on the data of glyceride composition at any stage of oil development (Kartha, 1964) and the pattern of fat metabolism during germination of coconut (Kartha, 1963).

Fatty acid composition of the endosperm:

In the developing fruit, the pattern of variation of fatty acids in both kernel and nut water appears to be similar although significant deviations in the relative abundance of component fatty acids have been found (Padua Resurreccion and Banzon, 1979; Jayalekshmy et al., 1988) (Fig. 5). In general the relative proportions of fatty acids upto C 14:0 increase during maturation while a corresponding decrease in the higher unsaturated fatty acids occurs. The most characteristic feature is that the content of lauric acid (C 12:0) in both the nut water and kernel rapidly increases with maturity upto 45% of the total in the mature nut while the contents of most other fatty acids

Fig. 5. Changes in fatty acids of (a) coconut kernel and (b) nut water during fruit ripening. (Refs: 5a: Padua-Resurreccion and Banzon, 1979; 5b: Jayalekshmy, Arumugham, Narayanan and Mathew, 1988)



remains far below 20%. At maturity, the two most prominent fatty acids in the endosperm are lauric acid and myristic acid. Since these two acids are intermediates in the biosynthesis of C_{16} and C_{18} acids, increased elaboration of C_{12} and C_{14} acids in the advanced stages of fruit ripening shows that any of the enzyme systems involved in the two-carbon-stage is elongation of the fatty acid chains can be selectively synthesized in the same depot (Kartha et al., 1959). Four of the fatty acids in nut water,

C_{14}:1, C_{15}:0, C_{16}:1 and C_{17}:0 which are present in the early stages disappear as the nut matures whereas the content of the short chain fatty acids, C_6:0 C_8:0 and C_{10}:0 which are present in negligible levels initially, rises with maturity in both the water and kernel. The long chain fatty acids C_{18}:3 and C_{22}:0 have been found at all stages of fruit growth in nut water (Jayalekshmy et al., 1988) but not in the kernel (Padua-Resurrection and Banzon, 1979; Balachandran, Arumugham and Mathew, 1985). Traces of linolenic acid have also been reported to be present (Udayasekhara Rao and Srinivasa Rao, 1981). In the mature nut, saturated fatty acids, mostly of short and medium chain length, like caprylic (C_8:0), Capric (C_{10}:0). lauric (C_{12}:0) and myristic (C_{14}:0 comprise nearly 83% (Table IV). This special feature of coconut oil, in which medium chain fatty acids predominate, is believed to give substantial health benefits when used as a dietary fat. Since metabolism of these medium chain fatty acids in the system releases energy and does not induce fat deposition, the belief that coconut oil promotes heart ailments has to be further investigated.

Table IV. *Fatty acid composition of coconut oil*

Fatty acid	Carbon chain length	Per cent
Caproic	6:0	0.5
Caprylic	8:0	6.5
Capric	10:0	6.0
Lauric	12:0	49.5
Myristic	14:0	19.5
Palmitic	16:0	8.5
Stearic	18:0	2.0
Oleic	18:1	6.0
Linoleic	18:2	1.5

Source: Kaunitz (1972)

Composition of fats in different layers of the kernel:

Variations exist in the proportions and properties of fats at different locations of the developing coconut (Kartha, 1963; Lim and Banzon, 1983). A marked concentration gradient for all the major constituents across the endosperm from the region surrounding the water cavity to testa has been reported. The inner layer of the kernel near the water cavity contains higher concentration of C_6:0 to C_{12}:0 fatty acids while the region near the testa is richer in long chain saturated and unsaturated fatty acids (Balachandran et al., 1985). Heathcock and Chapman (1983) have provided evidence for a marked gradation in size, shape and number of cells from the inner to outer regions of the endosperm. Their studies revealed that adjacent to the brown testa (outer region) cells are rigid, compact and lipid filled while those cells lining the central water filled cavity (inner region) have thin, easily deformed cell walls and contain little lipid. The testa oil composition shows extreme variations from oils of the other regions (Balachandran et al., 1985).

Hormones in the developing fruit

Following the observations of Van overbeek, Conklin and Blakeslee (1941) on the growth-promoting effects of coconut water studies on the identification of chemical constituents began in the early 1950's. To date, several growth promoters have been isolated in pure form from various parts of the coconut fruit (Table V).

The role of hormones in the coconut fruit maturation is probably to create sink activity and in the regulation of physiological and biochemical differentiation within them (Van Die, 1974). It is not known whether these hormones are synthesized in the nut or are imported as such through the phloem able V. *Growth promoters in the developing fruit*

rowth promoter	Source tissue	Reference
1, 3-diphenylurea	Liquid endosperm	Shantz and Steward (1955)
Gibberellin-like activity	Solid endosperm, Liquid endosperm, Embryo	Radley and Dear (1958)
Myo-inositol, Scyllo-inositol Sorbitol	Liquid endosperm	Pollard, Shantz and Steward (1961)
Phyllococosine (Leaf growth factor)	Liquid endosperm	Kuraishi and Okumura (1961)
Purne-like substance	Solid endosperm	Shaw and Srivastava (1963)
9-D-Ribofuranosyl Zeatin	Mature nut	Letham (1967)
Zeatin	Mature fruit, Liquid endosperm	Zwar and Bruce (1970)
Zeatinriboside	,,	Van Staden and Drewes (1975) Letham (1974)
Auxin-gibberellin like substances	Liquid endosperm	Van Staden and Drewes (1975) Dix and Van Staden (1982)

sap although available evidence in *Yucca* indicates that a cytokinin is translocated as a nucleotide in the phloem exudate (Vonk, 1974). More information on the developmental changes and role of hormones in nut maturation are warranted.

Growth inhibitors

It is interesting to note that the mature coconut water also exhibits growth inhibitory properties (Ultaman, 1949; Ramakrishnan and Ramakrishnan, 1949; Wilson and Cutter, 1952; Hegarty, 1955). It has been observed that inhibitory factors develop in the water and kernel as the fruit matures and functions in initiating and maintaining the dormancy of the embryo. The fruit contains a carefully poised complement of stimulators and inhibitors. Any shift in their relative proportions could be crucial in the overall regulation of germination and the timing of various metabolic events which occur during germination.

Other constituents

The developing coconut contains many other compounds having specific biochemical roles. Among these, shikimic acid and quinic acid are found at all stages of fruit growth. It is possible that these acids are involved in aromatic biosynthesis (Anonymous, 1961). Buttons of the green variety contain leucocyanidin and leucopelargonidin while the Red dwarf contains small amounts of flavonoid pigments in addition to leucoanthocyanidins (Nair and Sankara Subramanian, 1963). Mature coconut contains a number of vitamins in which ascorbic acid is the major component (2.2 – 3.7 mg/100 ml) Vanderbelt, 1985; Jayatilake, 1974; Grimwood, 1975). Appreciable quantities of silica have been detected in both kernel and water of coconuts collected from some parts of Kerala (Pillai, 1967).

Lysophosphatidylethanolamine comprises about 23% of all phospholipids in coconut kernel. The rest of the phospholipids are composed of phosphatidyl inositol, phosphatidylserine, phosphatidyl choline, phosphatidylethanolamine and other unidentified phospholipids in equal abundance (Monera and del Rosario, 1982). Coconut water contains an RNA, probably of low molecular weight, in the soluble form and is found to be not associated with any cell organelles (Mondel, Mandel and Biswas, 1970a). Phytin is reported to be present in coconut water and its role in supplying phosphate for the synthesis of nucleic acids has been demonstrated (Roychaudhury and Biswas, 1962).

CONCLUSIONS

The present status of knowledge of the developmental changes during fruit maturation in coconut justifies the existing practice of harvesting the nut at 11th month after pollination in Kerala. This is the stage at which the oil synthesis is nearly complete and the husk is still green; two factors which are of major concern from an industrial point of view. In order to effectively utilize the fruit components for specific end uses in the industry, more should be learnt of the varietal variations in the composition of fatty acids and proteins in the kernel and of nut water in terms of the content of sugars, vitamins etc. Since large quantities of the fruit is used in daily foods, attempts should be made to develop varieties for higher methionine content of coconut meal. The effect of various environmental and soil factors on the growth of the fruit requires careful analysis in order to determine the possible environmental modifications of the genetically controlled fatty acid patterns (Canvin, 1965, Hitchcock and Nichols, 1971). The identification of precise sites in the cell where the synthesis of fatty acids takes place is an important area for further investigations. Selection for reduced phospholipid content in oil, which are responsible for gumminess is desirable.

The molecular mechanisms of action of growth promoters in enhancing sink activity for fruit development and their possible role, if any, in seed germination and early seedling growth have to be explained. The contribution of husk pigments towards the development of nut is an important area needing investigation.

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